GUIDELINES FOR THE SELECTION OF AN INTERCHANGE CONFIGURATION

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BY

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JHRP

JOINT HIGHWAY RESEARCH PROJECT

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INDIANA STATE HIGHWAY COMMISSION

Final Report

GUIDELINES FOR THE SELECTION OF AN INTERCHANGE CONFIGURATION

TO: J. F. McLaughlin, Director
Joint Highway Research Project

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

September 14, 1973

Project: C-36-68C

File: 3-6-3

The attached Final Report titled "Guidelines for the Selection of an Interchange Configuration" has been authored by Mr. Thomas E. Mulinazzi, Graduate Instructor on our staff, under the direction of Professor G. T. Satterly, Jr. The research and report were conducted by Mr. Mulinazzi as non-sponsored research in the School of Civil Engineering at his expense and time in addition to his full-time duties in teaching and other research. He also utilized the research report as his Ph.D. thesis.

The objectives of the research was to develop an interchange design philosophy, to establish a set of evaluation criterion and to develop an evaluation methodology which would aid in the selection of the type of interchange at any particular location. These objectives were realized. A set of interchange design principles and an evaluation methodology were developed which will permit an effective selection of the optimum interchange configuration. An example which illustrates the use of the proposed methodology is included.

The Research Report is presented to the Board as information.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

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by

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Joint Highway Research Project

Project No.: C-36-68C

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September 14, 1973

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF DEFINITIONS

Interchange is a grade-separated intersection with interconnecting roadways (ramps) for turning traffic between highway approaches.

System Interchange is an interchange between two access-controlled facilities, and through which all movements are free flowing.

Service Interchange is an interchange between an access-controlled facility and a non-access controlled facility, and through which stop controlled terminals on the crossroad are allowed.

Parclo A is a partial cloverleaf interchange with two loop ramps which both serve as on-ramps to the freeway.

Parclo B is a partial cloverleaf interchange with two loop ramps which both serve as off-ramps from the freeway.

Parclo A-B is a partial cloverleaf interchange with two loop ramps, one which serves as an on-ramp to the freeway and the other as an off-ramp from the freeway.

Parclo A-4 and Parclo B-4 are partial cloverleaf interchanges similar to the parclo A and parclo B interchanges, respectively, but with diamond type ramps (direct connections) in the vacant two quadrants.

Trumpet A is a three leg interchange with a loop ramp serving as an on-ramp to the freeway.

Trumpet B is a three leg interchange with a loop ramp serving as an off-ramp from the freeway.

Loop or Leaf Ramp is a ramp on which a motorist must drive through a 270 degree curve to make a left turn.

Semidirectional or Jughandle Ramp; is a ramp on which the motorist must first maneuver right to make a left turn or vice versa for a right hand turn.

Directional Ramp is a ramp on which the motorist turns left to go left and right to go right.

ABSTRACT

Mulinazzi, Thomas Ernest. Ph.D., Purdue University, August 1973. Guidelines for the Selection of an Interchange Configuration. Major Professor: Gilbert T. Satterly, Jr.

The objectives of this research were to develop an interchange design philosophy, to establish a set of evaluation criterion, and to develop an evaluation methodology which would aid in the selection of the type of interchange for a particular location. It was not the intent of this research to develop a rigid procedure to determine the type of interchange, but rather to put forth a methodology for the design of interchanges.

The interchange design philosophy evolved into eighteen basic design principles and eight secondary design principles. These design principles formed the basis for two types of evaluation criteria; operational and design factors, and community disruption factors.

The evaluation methodology for selection of an interchange configuration which was developed in this research is divided into four parts: 1) scrutinize the evaluation criteria to determine which ones are relevant; 2) estimate the initial cost of each reasonable alternative interchange design; 3) develop an Effectiveness Profile for each such

alternative design; and 4) compare the initial cost and the Effectiveness Profile for each alternative design and select an interchange configuration. An example of the comparison of alternative interchange designs when both market and nonmarket factors are considered, is presented to illustrate the use of the evaluation methodology.

CHAPTER 1: INTRODUCTION

Statement of the Problem

The motor vehicle has become the major means of moving people and goods in our highly mobile society. To provide effective passageways for these vehicles, the engineer has developed a network of roadways which vary from local streets to freeways. The freeway is built as a limited access roadway on which vehicle entry and exit are restricted to only a few locations called interchanges. With various combinations of ramps and grade separations at the junction of two or more highways, interchanges are usually the weakest links in any freeway network because of the friction caused by the merging, diverging and weaving maneuvers associated with transposing traffic. From an operations standpoint, a freeway without any interchanges would be most efficient; however, system interchanges and service interchanges are required to meet the demands of the traveling public.

Interchanges are important, complicated and costly. Many factors, qualitative as well as quantitative, must be considered when designing an interchange. The Virginia Highway Department's Design Manual says, "The proper design

of an interchange depends upon many factors, the prime factor being the selection of the proper type of interchange."[1] Both Hong[2] and Leisch[3] have echoed this view; the major problem of interchange design is the selection of the proper type of interchange at a given location.

Under the present day methodology of freeway design, the selection of a particular type of interchange at a particular location is one of the last decisions made in the preliminary design process. The first step is to select a corridor through which the freeway should be located. Next an analysis is made of several alternate routes resulting in the selection of a preferred route. At this point checks are made to see that there are no obvious constraints to the placement of the proposed interchanges - location, not types of interchanges. In many cases, the final center line of the new facility is located without determination of the types of interchanges that will adequately serve the traffic demands. As a result, sometimes it is impossible to build the most adequate interchange at a particular location. It should be the practice that the interchange design engineer coordinate with the route location engineer at the earliest stages of the freeway's development so as to have a positive input in the actual location of the freeway at interchange locations. This process is referred to as

pre-preliminary functional design by Leisch.[4]

Another concept that is not always followed is the systems approach to interchange design. Much too often an interchange is designed as an isolated entity with respect to the rest of the freeway and especially to the crossroad. Improper weaving distances, impossible situations to sign, driver confusion from the lack of uniformity and impaired traffic operations have resulted both on the freeway and the crossroad. Some interchange designers go as far as to recommend that the type of interchange at a particular location be governed by the type and functional purpose of the crossroad.

Many agencies which have the responsibility for selecting the particular type of interchange to be used at a specific location seem to have their own preference of interchange type. Some state highway departments favor exclusive use of the diamond interchange; others favor some variation of the cloverleaf; and still others seem to arbitrarily select the type of interchange to use at a particular location. On the other hand in some highway design agencies, interchanges are justified primarily on the basis of specific geometric design criteria, total construction costs, traffic service requirements and/or potential road user benefits. Little consideration is given to the factors of:

1. physical and cultural controls
2. esthetics
3. existing and future arterial street systems
4. uniformity of interchange patterns
5. feasibility of stage construction
6. flexibility to accommodate unforeseen demands
7. signing and other safety considerations
8. present and anticipated land use adjacent to the interchange

In urban areas, especially where a freeway frequently attracts more trips than it has capacity to accommodate, the problem is not so much being able to justify an interchange, but rather determining which interchanges to provide and having done this, to select the type of interchange that would best serve the traffic and fit the site conditions.

Vast amounts of money have been spent in the construction of interchanges on the interstate system and on other high-type highway facilities. Even though the construction of the interstate system is coming to an end, there will be no end to the construction of new interchanges on access controlled facilities or the reconstruction of existing congested interchanges.

Objectives

One objective of this research was to develop a practical, general design philosophy for interchanges. This philosophy is based on the systems approach to design, considering both the freeway and crossroad facilities as well as adjacent interchanges and the network of local streets, all of which form the "driving environment" for the travelling public.

Another objective of this study was to establish evaluation criteria which could be used in the interchange selection process. The evaluation criteria distinguishes between Operational and Design Factors and Community Disruption Factors. The purpose of having lists of criteria is to give the interchange design engineer a check list against which to judge the effects of his design.

The final objective of this research was to develop an evaluation methodology which can be used by the state highway departments and other agencies responsible for the design of interchanges. This evaluation methodology can serve as a decision tool to aid in determining the type of interchange best suited for a particular location. It was not the intent of this research to spell out in absolute terms what type of interchange must be used, but rather to put forth an interchange design philosophy which, if followed, will result in "good" interchange design.

CHAPTER 2: REVIEW OF LITERATURE

General

A review of the literature reveals a lack of current research in the area of interchange selection procedures. Most of the significant work was done before the mid 1960's.

There is no one source which contains all of the pertinent information needed by the highway design engineer to select the proper interchange for a given location. Most of the literature has dealt with one design element of an interchange and analyzed this particular design element from a traffic operations standpoint. For example, the Texas Transportation Institute has conducted exhaustive research in the area of on-ramp merging techniques, including ramp metering.[1,2]

Interchange Selection Process

Loutzenheiser gives several fundamental rules which should be used in determining the type of interchange.[3]

1. Simplest type that will adequately serve the traffic needs.
2. Economy in first costs.
3. Urban land is irreplaceable.
4. The type of interchange must be realistic with regard to the type of operation on and the ultimate capacity of the crossroad.
5. Consistency in the general type along a freeway means greater safety and efficiency.

He also goes on to state that in general the determination of an interchange type is governed by the following parameters:

1. The design hourly volume of both through and turning movements.
2. The topographical and developmental controls at the site.
3. The crossroad operating conditions.
4. And, perhaps most importantly, the initiative of the design group.

Leisch[4] stresses three design objectives for interchanges in many of his articles. These objectives are simplicity, regularity, and uniformity. By simplicity Leisch means that the interchange configuration should be designed so that it is operationally simple with easy driver comprehension. Regularity means a conventional form such as no oddly shaped ramps; no odd number of ramps; and no left hand ramps. Factors providing uniformity include all right hand exits and all one exit designs. Leisch is emphatic in the belief that although a designer must follow a set of standards, these standards should just give him direction. It is the design philosophy behind these standards and how the designer applies this philosophy that makes the difference. One can follow a set of standards for an interchange; one can design the correct curvature, superelevation, etc.; but how these design elements are put together and also the conceptual aspects of the design, which are not clearly defined or spelled out in the standards, may be the important

considerations. The designer may not get all factors properly coordinated and actually arrive at a beautiful design from one point of view; for example, the least expensive design, but conceptually it may be poor because he did not consider certain operational experience or research of which he should have or could have been aware. The designer must be current in his technology and flexible to changing concepts.

Hall believes that the following are key words which must be kept in mind when making interchange design decisions:[5]

1. Simplicity
2. Consistency
3. Flexibility
4. Aesthetics
5. Safety
6. Economics
7. Traffic forecasts
8. Local street pattern
9. Freeway design elements
10. Terrain, churches, schools, railroads, etc.

He feels that the key to good interchange design is an ability to adequately consider all pertinent data which include the following:

1. Field review, a must to get a general sense of the location or a feel for the area.
2. Traffic requirements, which include design year predictions or even earlier traffic volumes, if necessary.
3. Existing and planned local road systems, which may be obtained from a master plan.
4. Social and environmental factors, which are inputs from the community.

Fites and Jacobs[6] list the following factors which affect the type of interchange selected:

1. Speed
2. Volume
3. Composition of Traffic
4. Number of Intersecting Legs
5. Standards and Arrangement of Local Streets
6. Topography
7. Right-of-way Controls
8. Local Planning Values
9. Proximity of Adjacent Interchanges
10. Community Impact
11. Cost.

They also stress the importance of designing an interchange to practical measurements and avoiding isolated ramps or partial interchanges to reduce driver confusion and increase safety.

Some of the state highway design manuals also list factors which affect the type of interchange selected, but most of the factors in these lists are included in Fites and Jacobs' list above.[7, 8, 9, 10, 11, 12] However, additional factors which are referred to in some of the state highway manuals are: continuity, geometric criteria, consistent ramp patterns, required capacity and existing and proposed land use.

Tutt,[13] in developing some guides for the selection of freeway interchanges, states that the determination of what design to use for a particular location must be based on the demands of the traffic to be served, with the volume of the left turns and the means used to eliminate the conflicts caused by these left turns determining the type of interchange facility.

Hill[14] summarizes some of the important factors in freeway interchange design as invisioned by the California Highway Department.

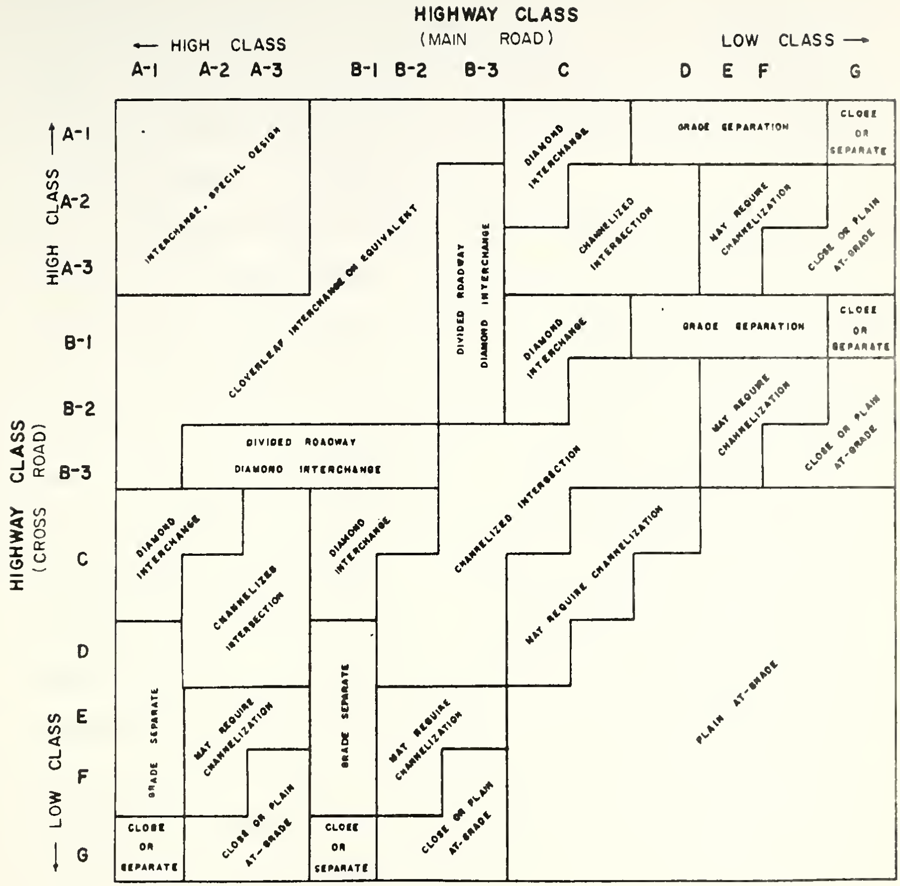
1. Avoid weaving to provide for major turning movements and scrutinize carefully all freeway designs for possible restrictive weaving sections.
2. Present the freeway driver with only one decision at a time, separate decisions by a reasonable distance to allow for adequate reaction time.
3. Turning movements should normally be made from the right lane and should require positive action by the driver.
4. The motorist should be presented with consistent familiar situations at points of decisions.

The Manual of Geometric Design Standards for Canadian Roads and Streets[15] stresses that the interchange design selected should be based primarily on traffic requirements, and not on construction and property costs, because interchanges are permanent installations and designs have too often been chosen on cost factors alone, resulting in an inadequate facility which in time must be changed. The final design should depend on traffic requirements, property costs, road classification, and physical limitations.

The New York State Highway Department[16] has gone a step further and developed a list of preferred design principles for interchange design. In an approximate order of importance, these principles are as follows:

1. minimum weaving
2. single exits (one exit policy)
3. no left-hand exits or entrances
4. exits precede entrances
5. single entrances
6. desirable ramp design speed
7. desirability of placing crossroad over main line
8. uniformity of operation
9. grading of interchange area

In the current Illinois Highway Design Manual[17] there is a general guide for the selection of interchange types in rural areas. This guide is reproduced in Figure 1.



Trunk Highway Class

A-1: Over 1900 DHV (one way)
A-2: Under 1900 DHV (one way)
A-3: Under 850 DHV (two way)

Major Highway Class

B-1: Under 1900 DHV (one way)
B-2: Under 850 DHV (two way)
B-3: Under 750 ADT

Collector and Land Access

C: 400-1425 DHV (two way)
D: 200-400 DHV (two way)
E: 100-200 DHV (two way)
F: 250-400 ADT
G: Under 250 ADT

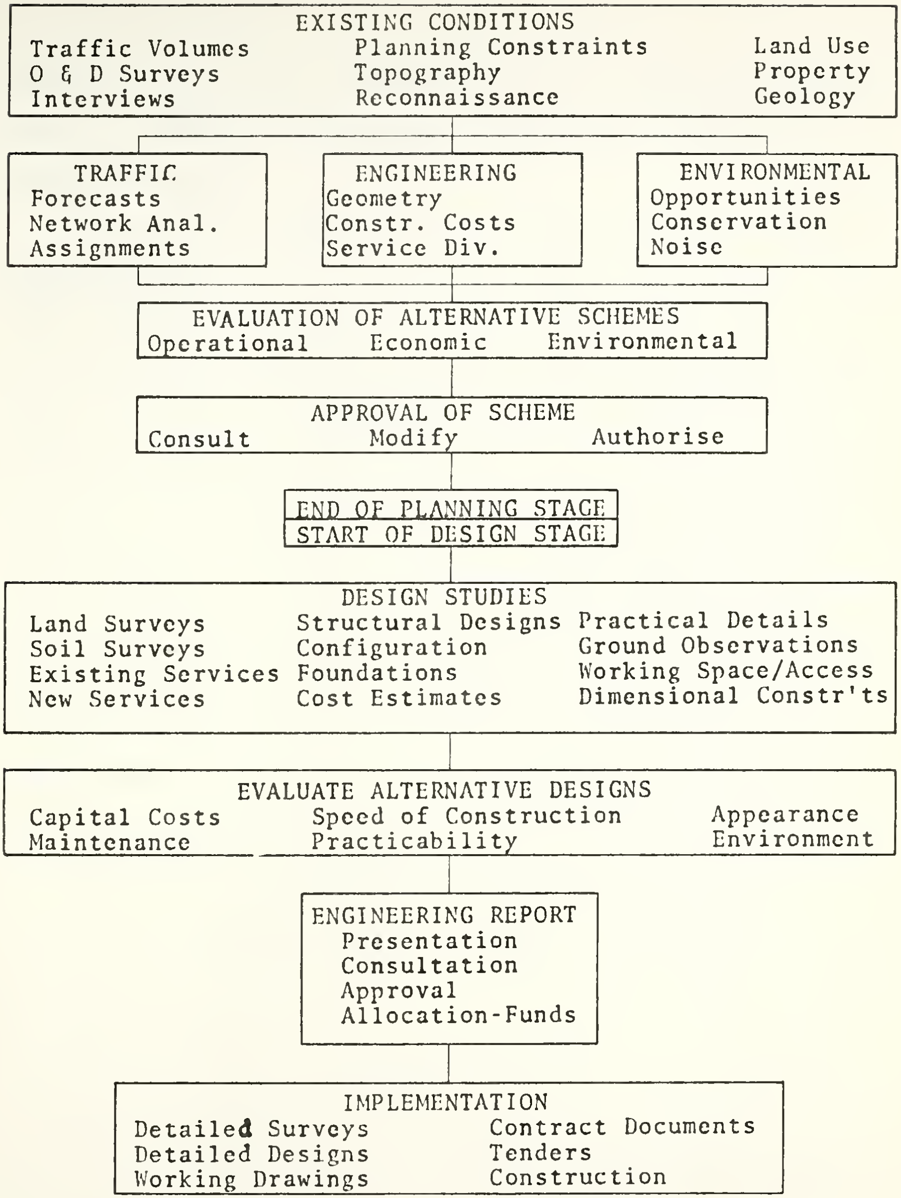
Source: 17, p. 3-201.02

FIGURE 1 RURAL INTERSECTION TREATMENT - ILLINOIS

Although the Illinois Design Manual explicitly states, "it is used for preliminary planning only", this table has often been taken as official state policy. This figure is being eliminated from the Illinois Highway Design Manual in the current revision process.

Two state highway departments have attempted to quantify, to some extent, the process of determining the proper interchange configuration. Illinois[18] and Virginia[19] have developed procedures which dictate when a loop ramp is required because of conflicting movements on the crossroad. Illinois' procedure, the "500 Cross Conflict Analysis", analyzes the diamond ramp terminals on the crossroad. When the sum of the left turn and through movement conflicts is greater than 500 vph and the left turn volume is greater than 60 vph, then a loop ramp is provided to eliminate the left turns off of the crossroad. The State of Illinois is tending away from this method because it is based solely on traffic volumes and does not consider other characteristics of the site. Virginia's policy is basically the same except 600 conflicts are used as the break point.

Best developed a simple flow chart (see Figure 2) for the planning and design of urban interchanges. He realized that "although many comparative design features cannot easily be quantified, there should be a systematic analysis of all feasible solutions."[20] With this in mind, he



Source: 20, p. 43

FIGURE 2 FLOW CHART FOR THE PLANNING AND DESIGN OF URBAN INTERCHANGES

prepared Table 1 which illustrates which principle features should be compared even though many of the features have subjective impacts.

Gannett, Fleming, Corddry and Carpenter[21] developed a Prospectus containing a diagram for major interchange optimization in response to an F.H.W.A. request for proposals entitled Major Interchange Design, Operation and Traffic Control. This diagram, shown in Figure 3, lists many factors which should be considered in the optimization of a major interchange design, including eleven variables which directly influence the interchange configuration.

Leisch also has developed a specific list of criteria to use in the evaluation of different interchange configurations.[22] His criteria are subdivided into four categories.

I. Operational Characteristics
   A. Speed of operation
   B. Travel distance, and rise and fall
   C. Safety aspects - comprehensive and anticipatory qualities
   D. Safety aspects - others
   E. Capacity

II. Costs
   A. Capital costs
   B. Operating costs

III. Implementation Characteristics
   A. Adaptability to construction staging
   B. Maintenance of traffic during construction

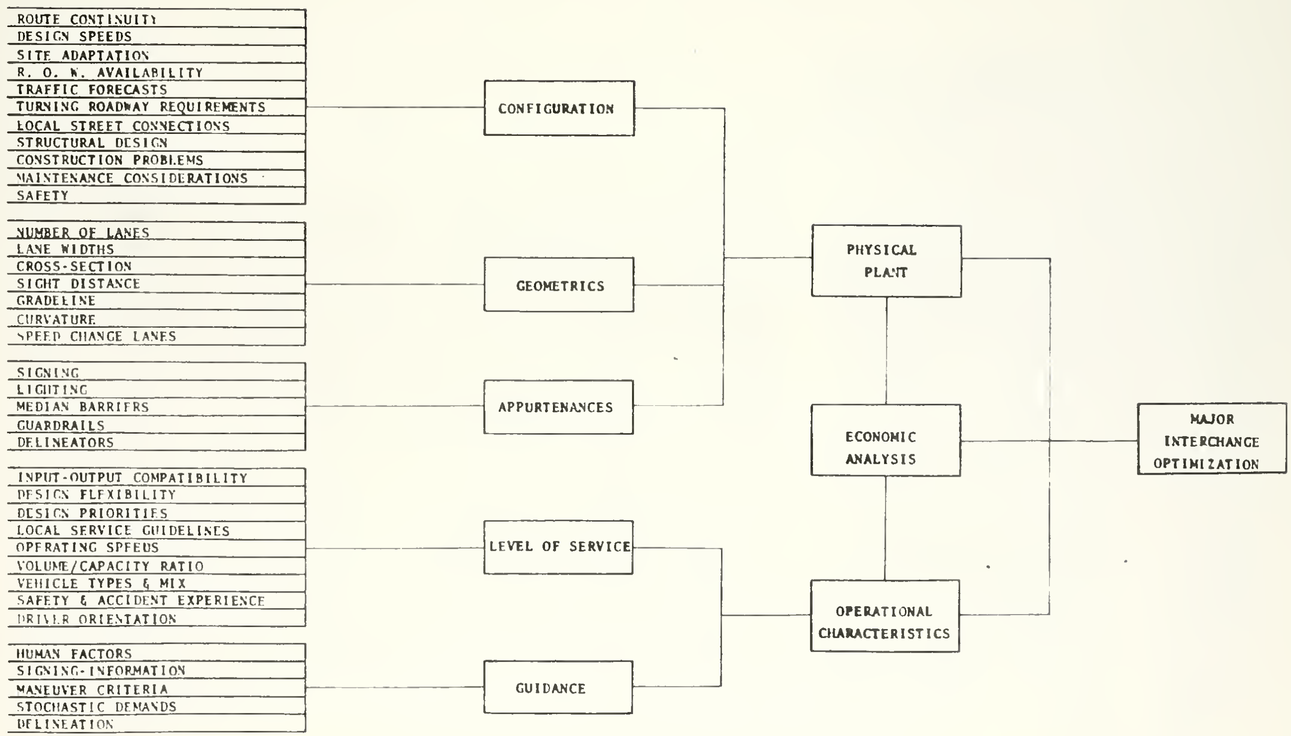
IV. Environmental Considerations
   A. Traffic disturbances
   B. Aesthetic qualities
   C. Barrier effect
   D. Impact on development

TABLE 1

FACTORS TO CONSIDER IN THE COMPARISON OF INTERCHANGE TYPES

Source: 20, p. 45

FACTOR	EVALUATION
<u>Planning</u>	
Properties affected	
Displaced population	
Barrier effect	Mainly subjective aided by numerical data
Noise	
Effect of adjacent areas	
Future land use opportunities	
Landscaping opportunities and costs	
Over-shadowing	
Disturbance of amenity	
<u>Land and Property Costs</u>	
Land	
Demolition	Numerical
Rehousing	
Accommodation works	
<u>Engineering</u>	
Construction costs	
Diversion of services	All numerical with some subjective evaluation of traffic operation and safety
Geometric standards, safety, and design speed	
Lighting costs	
Road heating costs	
Ventilation (if in tunnel)	
Traffic operation characteristics	
Operating costs	
Maintenance	



SOURCE: 21

FIGURE 3 MAJOR INTERCHANGE OPTIMIZATION

Preliminary Design Procedures

The AASHO "Red Book" gives the following procedure for preliminary interchange design:[23]

> This section outlines the design procedure which has been found most desirable for preliminary interchange design. When followed and the recommended guides and practices of geometric design given in the proceeding parts of this chapter (Chapter J) are applied properly to each feature of the interchange, the most appropriate design is assured. The procedure assures complete coverage of all aspects of interchange design and avoids needless refinement in the preliminary study states.
>
> A. Basic data for design
> 1. Obtain and analyze traffic data to determine DHV for all through and turning movements including future expansion.
> 2. Obtain physical data for the site including maps showing topography, culture, and plats showing existing buildings and those likely in the future.
> 3. Determine the location, type, and general design features of all highways and other development both existing and planned in the area which may have a bearing on the design.
>
> B. Preliminary design
> 4. Prepare study sketches for several likely interchange layouts that are suitable to meet traffic needs and are practical for the site and design controls.
> 5. Analyze alternate schemes and select two or more for further study and for preparation of preliminary plans and profiles.
> 6. Prepare preliminary plans and profiles for the alternates selected under 5.

C. Determination of preferred plan
   7. Evaluate each alternate preliminary plan with respect to design features, capacity vs. volume, operational characteristics, overall adaptability, maintenance of traffic during construction, and suitability to stage construction.
   8. Make preliminary estimates of cost for each alternate preliminary plan, including land acquisition, clearing the site, construction, maintenance, utility changes, maintenance of traffic during construction, etc.
   9. Calculate annual road user costs and road user benefit ratios for each alternate preliminary plan.
   10. Analyze steps 7, 8, and 9 jointly and reach conclusions as to the preferred plan.

D. Final design
   11. Prepare construction plans, specifications, and estimates.

Some state highway departments have quoted this procedure in their highway design manuals.[24, 25]

The Manual of Geometric Design Standards for Canadian Roads and Streets[26] also has basically the same outline for a preliminary interchange design procedure. However, the Canadian Design Manual includes emphasis of three other considerations: 1. aesthetics of the alternative designs in relation to the surrounding area; 2. the feasibility of signing; and 3. the compatability with other interchanges on the roadway.

Malone[27] in his work with preliminary designs of free flow highway interchanges, takes a little different approach. His "rational" approach to the design of an interchange is as follows:

1. Obtain a topographical plan of the area on which are marked special foundation features and property limits or values. Note on the plan the design-hour left-turn movements.
2. Sketch in through movements on an overlay sheet assuming normal median widths.
3. Note on the plan for each left turn all of the basic left turns which will efficiently meet capacity requirements.
4. Eliminate any left-turn movements which are incompatible with property requirements.
5. Sketch on overlay the best two remaining types for each left turn using colored pencils for clarity.
6. Select the most compatible combinations, check to see if ramp profiles are reasonable, then make rough estimates of costs.
7. With each of the plans try each arrangement then with both widened, and check the approximate costs of each.
8. If wide medians have proven to be superior try transposed lanes and stacked lanes for any reduction in over-all costs.
9. With the best three plans, review all movements eliminated in steps 4 and 6.
10. Insert right turn movements at outer ramps, but check adaptability of these ramps, particularly if wide medians have been adopted.
11. Check to see if structures can be combined and then warp alignment of through roadways to ease left turns.
12. Prepare a detailed plan and cost estimates for the three best arrangements.
13. Make cost benefit analysis of each plan to determine cost benefit indexes. These indexes, combined with any other intangible benefits for each of the plans, should permit selection of the one best interchange arrangement.

Adaptability of Interchange Types

A few authors have taken the risk to develop tables and figures relating a particular interchange configuration to a given situation. Most of these tables relate the type

of interchange to the functional use of the crossroad facility for both urban and rural areas. Table 2, as an example, is taken from the Manual of Geometric Design Standards for Canadian Roads and Streets.[28] This example goes further and relates the five possible ways of accomplishing a left-turn under a free flow condition to operational, economic, and geometric characteristics. This information is shown in Table 3. Malone[29] expanded Table 3 to include the two typical left-turn stop movements as shown in Table 4. He classifies these as Stop-A and Stop-B movements. A Stop-A movement is characteristic of the Diamond and the Parclo-A; Stop B of the Diamond and the Parclo-B. As "stop-condition" movements these are not applicable to free flow interchanges except in very special cases.

Leisch[30] pictorially shows the adaptability of interchanges on freeways as related to type of intersecting facility in Figure 4. It is interesting to note that Leisch recommends all one-exit, right-hand-exit interchanges.

Love gives a warning to all design engineers concerning standard interchange designs.[31] He says, "Although standard interchange designs are desirable as guides, they should not be utilized as the sole basis for design. All interchanges should be considered as individual problems with due consideration given to all types of interchange designs and to all factors that must be evaluated before a

TABLE 2 ADAPTABILITY OF INTERCHANGE TYPES

Source: 28, p. 176

Type of Crossroad Facility	Left Turn Volumes	Urban Freeway	Rural Freeway
Collector	Low	At-grade only	Parclo B
	Medium	Diamond* or Parclo A4 or B4#	Parclo A4 or Parclo B
	High	Diamond* or Parclo A4 or B4#	Parclo A4
Arterial	Low	Diamond	Parclo A4
	Medium	Parclo A4 or Diamond*	Parclo A4 Free Flow
	High	Free Flow	Free Flow
Freeway	Low	Free Flow	Free Flow
	Medium	Free Flow	Free Flow
	High	Free Flow	Free Flow

*May require variations of the Diamond Type Interchange.

#Only when property prevents use of a Parclo A4.

TABLE 3 CHARACTERISTICS OF LEFT-TURN MOVEMENTS FREE-FLOW INTERCHANGES

Source: 28, p.178

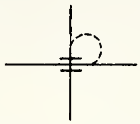
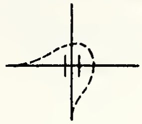
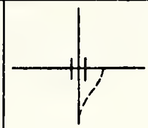
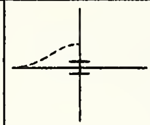
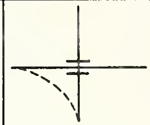
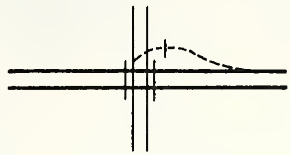
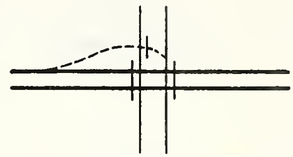
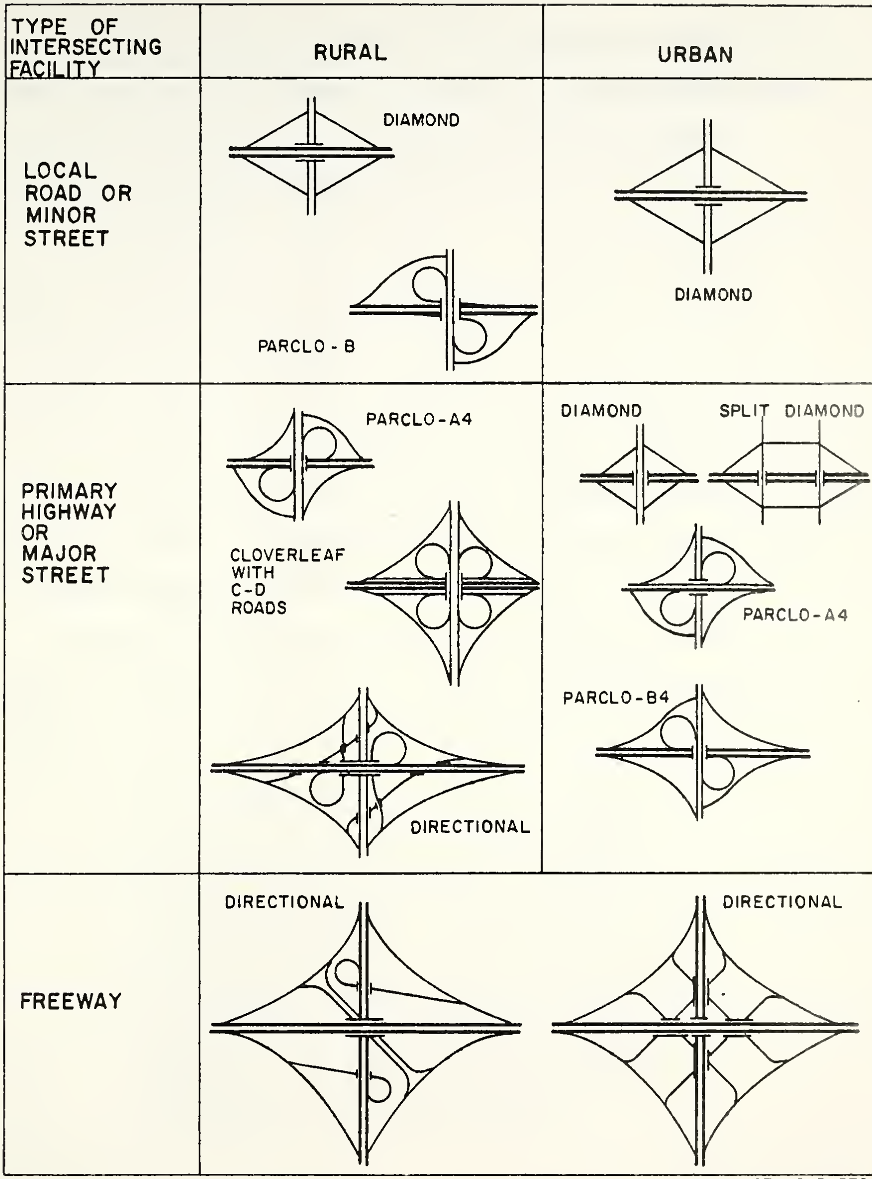
TYPES	LOOP	CIRCLE	SEMI-A	SEMI-B	DIRECT
					
CAPACITY	LOW	MEDIUM	MEDIUM	MEDIUM	HIGH
SPEED	LOW	MEDIUM	MEDIUM	MEDIUM	HIGH
TRAVEL TIME	HIGH	HIGH	MEDIUM	MEDIUM	LOW
RT. EXIT & ENTRY					
NARROW MED. <60°	YES	YES	YES	YES	YES
WIDE MED. >60°	YES	YES	NO	NO	NO
COSTS					
CONSTR.	LOW	HIGH	MEDIUM	MEDIUM	HIGH
PROPERTY	HIGH	HIGH	MEDIUM	MEDIUM	LOW
WEAVING	LOOPS SEMI A SEMI B	NO	LOOPS SEMI B	LOOPS SEMI A	NO
SKEWED XINGS					
> 90°	POOR	GOOD	POOR	POOR	GOOD
< 90°	POOR	GOOD	VERY GOOD	VERY GOOD	GOOD
ONE EXIT					
NARROW MED.	YES(CD)	YES	YES	NO	YES
WIDE MED.	YES	NO	YES	NO	NO

TABLE 4 ADDITION TO TABLE 3
CHARACTERISTICS OF LEFT-TURN MOVEMENTS

Source: 29

TYPES	STOP - A	STOP - B
		
CAPACITY	VERY LOW	VERY LOW
SPEED	VERY LOW	VERY LOW
TRAVEL TIME	VERY HIGH	VERY HIGH
RT. EXIT & ENTRY		
NARROW MEDIAN	NO	NO
WIDE MEDIAN	NO	NO
COSTS		
CONSTRUCTION	VERY LOW	VERY LOW
PROPERTY	VERY LOW	VERY LOW
WEAVING OCCURS	NO	NO
SKEWED XINGS		
> 90° TURN	GOOD	GOOD
< 90° TURN	GOOD	GOOD
ONE EXIT		
NARROW MEDIAN	YES	NO
WIDE MEDIAN	YES	NO



SOURCE 30, P 372

FIGURE 4 ADAPTABILITY OF INTERCHANGES ON FREEWAYS AS RELATED TO THE TYPES OF INTERSECTING FACILITIES

good design can be developed. When standard designs are used, there is a tendency to apply them indiscriminately, resulting in stereotyped plans which do not reflect professional engineering quality."

Use of diamond interchanges is strongly recommended by Barnett for both rural and urban locations.[32] These recommendations are made because of the ease in signing diamonds; the low cost of right-of-way; and less driver confusion due to the simplicity of design. Barnett does recommend, however, that the use of frontage roads and slip ramps be utilized in conjunction with diamond interchanges in urban areas to increase the capacity.

Pinnell and Buhr have completed extensive work on urban interchange designs as related to traffic operations. Their conclusions are as follows:[33,34]

1. Diamond type interchanges are simple, economical interchanges well adapted to urban conditions, vehicle operations and street system layouts. Where continuous frontage roads are used, interchanges must be basically of the diamond variety where they form an integral part of the design operational flexibility. Depending on the capacity requirements, a conventional diamond interchange, a split diamond interchange, a split diamond one way pair interchange, or a three level diamond interchange seems appropriate.

2. The large spatial requirements and serious capacity limitations of cloverleaf interchanges make this type rarely suitable for use in urban areas. However, in rural areas, it is a highly desirable type of interchange and when collector-distributor roads are incorporated in the design, it is well adapted to locations in suburban outlying areas.

3. The partial cloverleaf, or parclo type of interchange, is being used in many locations. The loops of the parclo-A are located in advance of the overpass; the parclo-B has its loops beyond the overpass. These interchanges are well adapted to intersections with minor rural roads. The parclo-A (4-quad) is preferred over the parclo-B (4-quad) because this type of interchange eliminates left-turns from the crossroad. The only left-turns that occur at grade are directly off the ramp. Contrary to common beliefs, the parclo-A (4-quad) does not have more capacity than a correctly signalized diamond interchange.

4. Directional interchanges are required at points of high traffic concentration, such as at the intersection of two freeways. Interchanges which have one direct or semi-direct connection for a left-turn movement are termed directional interchanges. There are many configurations for directional interchanges. It is left up to the design engineer to fit the best directional interchange to the given constraints or situation.

In the Highway Design Manual for the State of New York is a discussion of "preferred interchange types" for general situations.[35] The following is a summary of New York's recommendations:

A. Three-leg interchanges
   1. freeway-local road interchanges - trumpet A
   2. freeway-freeway interchanges - directional "T" or "Y"

B. Four-leg interchanges
   1. rural freeway with two lane rural crossroad - diamond interchange
   2. rural freeway with rural multi-lane primary highway - cloverleaf interchange with C-D roads on both facilities
   3. urban freeway with local street - diamond with frontage roads or split diamond without frontage roads
   4. freeway-freeway interchange - directional interchange or, in rural areas with light traffic, cloverleaf interchange with C-D roads on both freeways

Takebe[36] has stated that when a type of interchange is selected for a given condition, the most suitable type is adopted considering traffic operations and economy on the basis of the following:

1. types of intersecting highways
2. site conditions
3. traffic volumes

Takebe believes that, "the patterns commonly adopted to the most frequently encountered conditions seem to be few in number, probably 15 to 20."[37]

<u>Current Design Trends for Interchanges Based on Operational Experience</u>

Freeway interchanges are like people, they pass through youth, maturity and finally old age; but interchanges reach the age of senility less from passage of time as from the growth of traffic volumes. Interchanges are planned for

traffic forecasted for the next 20 to 25 years, however, conditions can change which would completely alter the travel patterns. For example, an unforeseen industrial park or shopping center can metamorphose a functional interchange into an operational nightmare. According to Leisch[38] operational flexibility can be achieved in the following ways:

1. Judicious provision of the number and arrangement of lanes to allow for substantial variations in travel patterns.
2. Supplementary facilities providing alternative routes such as frontage roads.
3. Complementary public transportation.

The highway design engineer has learned from past experience that flexibility in the original design can save time and money when he is forced to upgrade or increase the capacity of an existing facility.

Interchange Spacing

The general concensus of the literature is that interchanges in an urban environment must never be spaced closer than 1/2 mile and preferably at 1 mile intervals.[39,40] In rural areas the absolute minimum is 2 miles and preferably at 5 miles. If the interchanges are too close, the freeway will become congested with local traffic using it as a collector-distributor facility. If the interchanges are

spaced too far apart, the traffic loads at isolated interchanges will become excessive. Some of the key factors in interchange spacing are:

1. land use,
2. topography,
3. street pattern,
4. geometric features, and
5. operational characteristics.

Signing

If a freeway is to function properly and especially if the interchanges are to be operationally acceptable, geometric design and signing must be integrated at the earliest possible time. A basic principle in geometric design is that the final and crucial test of an otherwise satisfactory design lies in the signing. Signing must be correlated with the geometric features of the freeway in the earliest planning and design stages. This problem of signing or driver information systems is often not given adequate consideration in interchange design. The philosophy of the past has often been that after the pavement is in place, then it is time to worry about signing.

There are some basic principles that should be followed in interchange signing.[41]

1. clear interpretations.
2. route continuity

3. advance notice to the driver.
4. relatability to maps, advertisements, tourist information, etc.
5. size, not only of the sign, but of the letters and words on the sign relative to emphasis.
6. unusual maneuvers should be emphasized.

Webb developes a signing design criteria, which includes the following elements[42]:

1. a need for providing continuity for sign routes
2. an allowance for all 12 traffic movements if at all possible
3. the avoidance of pulled apart interchanges because of the difficulty they create in directing traffic back to the freeway.
4. except for special conditions, entrances and exits should be on the right of through traffic.
5. adequate sight distance between ramps; 1000 ft. minimum between exits on the freeway and 600 ft. minimum between a freeway exit and a bifurcation on the collector road.
6. a provision for unimpaired visibility, whenever possible for exit ramps and their signs.
7. an allowance for adequate gore width on freeways where reflectorized signs are to be used.

8. avoidance of ramps for local traffic movements within an interchange area.
9. the provision for collector roads with cloverleaf type of interchanges wherever possible.

Several design elements are directly related to signing. These are alignment, speed, illumination, frequency of interchange and the interchange configuration. The question of signing seems very elementary; however, many complicated interchanges have been built which have been impossible to adequately sign.

Anticipatory Sight Distance

Leisch[43] introduces a new type of sight distance into interchange design. He believes that the driver should be able to anticipate the proper movement as he approaches an interchange and defines this as the "anticipatory sight distance." A good example of this is with a depressed freeway when the off ramp is on an upgrade and the approaching driver can see it from some distance. Leisch feels that this anticipatory sight distance should be in the range of two thousand feet in order to give the driver enough time to properly react to the approaching situation. Signing helps to convey this anticipatory sight distance to the driver but visual perception of the interchange configuration is the best situation.

Off-Ramp Design

Off-ramp design has been the subject of extensive research. Conklin, studying vehicle operating characteristics on exit ramps, found that the direct taper type of off-ramp was superior to the parallel type of ramp.[44] Similar findings resulted from the work of Fukutome and Moskowitz.[45]

Gray and Kauk did a study of vehicular operational characteristics on circular and elongated freeway exit loop ramps and concluded that circular loop ramp alignment is better than elongated loop ramps.[46]

Pinnell and Keese developed three general rules for exit design: 1. a natural exit path, 2. an adequate sight and deceleration distance,and 3. delineation of the ramp nose and exit area.[47]

An AASHO committee added a fourth general rule: 4. "the act of leaving the through lanes should be accomplished without slowing down, the deceleration being accomplished on the turning roadway or on a parallel deceleration lane after leaving the through traffic lanes." AASHO also recommends that this high speed exit be accomplished at a flat angle of 4 or 5 degrees.[48]

Roth, in an attempt to better delineate exit ramps, studied the use of color delineation lanes on the pavement.[49] His results showed a definite decrease in erratic driver movement, with more emphatic results obtained at the more complicated interchanges.

The question of ramp location relative to the cross road is often raised. The concensus in the literature is that it is usually better to locate off-ramps upstream from on-ramps, so as to eliminate the weaving section.[50,51] These studies indicate that a 50 to 70 percent increase in ramp capacity could be obtained by removing traffic in advance of adding traffic to the freeway.

Berry, Ross and Pfefer studied the use of left-hand exit ramps. They concluded that conditions may prevail which dictate left-hand exit ramps.[52] However, in general the literature indicates general opposition to the use of left-hand ramps because of driver confusion associated with left-hand ramps.

Another study has been conducted which evaluated ways to eliminate wrong-way entries onto off-ramps. The recommendation was to construct an "ear" or turnaround near the cross street terminal of the ramp which would head the wrong-way driver in the proper direction.[53]

The California Highway Department uses the value of 1500 passenger equivalent vehicles per hour as the design year volume when a two lane exit ramp is needed. For design year traffic volumes of between 900 and 1500 passenger equivalent vehicles per hour,a one lane exit ramp is recommended with provisions for adding an additional lane.[54]

On-Ramp Design

On-ramp design has also been a topic of continual research. Four basic rules are prevalent in most of the past studies:

1. On-ramp terminal design should be standardized,
2. A direct alignment should be provided,
3. The angle of convergence is an important control,
4. Adequate merging distance should be provided.

In general, two lane entrance ramps are usually warranted when the design volume exceeds 1500 vph. It has been found that such a design can be used to supply through roadway continuity, to meet lane balance requirements or to provide design flexibility. When the estimated design volume is between 900 and 1500 vph, a one lane entrance should be provided with the provision for future widening. With a two lane entrance, a 1000 ft. auxiliary lane should be provided beyond the point of merge of one lane.[55]

An important consideration which is stressed in much of the literature is the relationship of good entrance ramp terminal design with visibility; or the ability of through drivers to see the entering vehicle and the ability of the entering motorist to see the gap availability. Good visibility allows high speed entrance ramp movements and, when associated with a flat angle of entrance of about one degree, provides the best design. There should be no stop sign controls or any other warning or regulatory sign

except where visibility is not adequate.

Ramp metering has received considerable attention, especially in Texas and Illinois. This technique has proven to be a successful operational tool in increasing freeway capacity by reducing the conflicts caused by merging vehicles.

Weaving

The number of lanes through a weaving section can be determined by the following equation:[56]

$$\text{Number of Lanes} = N = \frac{V_{w1} + KV_{w2} + V_{o1} + V_{o2}}{SV}$$

where: V_{w1} = vph in the larger weaving movement

V_{w2} = vph in the smaller weaving movement

V_{o1} and V_{o2} = vph in outer flows

K = weaving influence factor

SV = appropriate service volume or capacity per lane on approach and exit roadways

However, current research at the Polytechnic Institute of Brooklyn[57] will likely result in recommended changes in the above method for number of lanes.

It is important to remember that weaving capacity should be specified at a particular speed. The Michigan State Highway Department[58] uses the following criteria. For urban situations, a minimum weaving speed of 35 mph and a level of service C with a service volume of 1200 vph

should be used. In rural areas the minimum operating speed should be 40 mph with a service volume of 1000 vph at a level of service C. When collector-distributor roads are provided, the weaving speeds for the urban and rural conditions can be reduced to 25 mph and 30 mph respectively, thus increasing the weaving capacity. For a level of service C, the weaving capacities become 1500 vph in urban areas and 1200 vph in rural areas.

The most prevalent weaving condition exists between adjacent loop ramps on a cloverleaf interchange without a collector-distributor road. In this case the weaving capacity is around 1000 vph; however, with the addition of a C-D road, the weaving capacity increases to about 1500 vph.

Some general rules to remember concerning weaving are: 1. slower speeds result in higher weaving capacity for a given length of weaving section; 2. avoid weaving sections if it is possible especially for high volume transfer points; and 3. the total number of vehicles passing through a weaving section cannot exceed the capacity of a single lane.[59]

Collector-Distributor Roads - Auxiliary Lanes

In this research collector-distributor roads are considered as a special form of auxiliary lanes. A C-D facility is often used when the following three conditions

exist: 1. a heavy weaving movement within an interchange; 2. decision points along a through roadway spaced closer than 1000 feet; and 3. entrances and exits spaced close together. In all cases the C-D facility serves as a buffer between the through traffic and the friction caused by the interchanging traffic.

Auxiliary lanes are added to the basic width of the freeway in order to provide satisfactory operating conditions. Auxiliary lanes have been used between an entrance ramp and a closely followed exit ramp (combined merging and diverging zone), to orient traffic to two lane exit ramps, and to maintain the concepts of lane balance and basic number of lanes.

Frontage Roads

The basic functions of frontage roads are to provide access to abutting property, to maintain traffic circulation on the local street system, and to provide operational flexibility to the freeway.

As a general policy, the Texas Highway Department constructs, or makes provisions for, continuous frontage roads on all access controlled highways, both in urban and rural areas.[60] Pinnell and Tutt have indicated that advantages in system flexibility, capacity, operations and construction have been obtained through the use of continuous one-way frontage roads.[61]

Some of the criticisms of frontage roads found in the literature concern themselves with excessive right-of-way costs, overloading of the intersection between the frontage road and the crossroad, conflicts with ramp terminals near interchanges, and usable land abutting on only one side of the frontage road which is not efficient design.

Crossroad

The important thing to consider when determining the effect of an interchange on the crossroad is that the level of service of the crossroad must be maintained through the interchange area. The interchange area must not become a bottleneck location for the crossroad.

An AASHO publication reports that engineers in several cities have expressed the opinion that "they could operate their streets well if called in at the early design stage to advise on the street and interchange design."[62] They believe that an intersection between a ramp and a street is as easy to operate as any at-grade intersection when not complicated by spacing the terminals too close together or placing the terminals too close to other signalized intersections.

Ramp Terminals at Crossroad

The main problem associated with ramp terminals at crossroads is caused by the situation when the intersection of the ramp and the crossroad must be signalized. The

design of the ramp terminals must be such so that multi-phase signalization is not necessary, if at all possible.

When additional capacity is needed at an intersection of a ramp and a crossroad, it can be achieved in the following ways:[63]

1. additional lanes on the crossroad
2. separate right and/or left turn lanes, flaring the ramp
3. channelization

The California Highway Department lists the following factors which influence the location of ramp intersections on the crossroad:[64]

1. sight distance
2. construction and right-of-way costs
3. circuity of travel for left turn movements
4. crossroad gradient at ramp intersections
5. storage requirements for left turn movements off the crossroad and
6. the proximity of other local road intersections.

Lane Distribution

Lane distribution has often been overlooked as a design element and, as a result, man-made bottlenecks exist on many of our freeways. The normal procedure for determining the required number of lanes is based on a volume to capacity relationship; when a certain v/c ratio

is attained for a given level of service, another lane is added. If this criteria is followed rigorously, an unbalanced lane distribution situation often results. The proper approach to solving this problem is to coordinate the concepts of basic number of lanes and lane balance.

A freeway is considered either a four lane freeway, a six lane freeway or an eight lane freeway. The number of through lanes normally associated with a given freeway is considered the basic number of lanes. Lane balance, on the other hand, is a concept that minimizes sudden and abrupt changes in the number of freeway lanes especially at merging, diverging and weaving areas. "The lane balance concept indicates that a certain relationship in the number of lanes must be maintained at points of merging and diverging traffic in order to produce smooth operating conditions and to fully realize the potential capacity."[65] By combining the two concepts of lane balance and basic number of lanes, the necessary balance between traffic volumes and level of service is provided while operational flexibility is also realized.

Through Lanes

Considerations of the through lanes in an interchange area center on the concepts of basic number of lanes, lane balance and route continuity. The California Highway Department states that lane reduction below the basic number

of lanes is not permissible through a local interchange.[66] Leisch believes that interchanges should be designed for the unfamiliar driver and, therefore, the continuation of a designated route should take precedence over larger volume movements.[67]

Environmental Considerations

After a series of Circular Memorandums, FHWA Notices, and Instructional Memorandums, the Federal Highway Administration (FHWA) on August 24, 1971 issued a Policy and Procedure Memorandum-PPM 90-1[68] which provides guidelines to highway departments to

> "assure that the human environment is carefully considered and national environmental goals are met when developing federally financed highway improvements. ... An environmental statement or combined environmental/section 4(f) statement or negative declaration, whichever is appropriate, shall be prepared and processed in accordance with this memorandum for each highway section proposed for construction with funds administered by the Federal Highway Administration .... on or after February 1, 1971.
>
> An environmental statement is a written statement containing an assessment of the anticipated signficant beneficial and detrimental effects which the agency decision may have upon the quality of the human environment for the purpose of:
>
> 1. assuring that careful attention is given to environmental matters,
> 2. providing a vehicle for implementing all applicable environmental requirements, and
> 3. to insure that the environmental impact is taken into account in the agency decision.

Section 4(f) of the Department of Transportation Act, as amended in section 18 of the Federal Aid HIghway Act of 1969, permits the Secretary of Transportation

> "to approve a program or project which requires the use of publicly owned land from a park, recreation area, wildlife and waterfowl refuge, or historic site ONLY if:
>
> 1. there is no feasible and prudent alternative to the use of such land, and
> 2. such programs include all possible planning to minimize harm to the section 4(f) land resulting from such use."[69]

These two documents, the environmental statement and a section 4(f) statement, have extended completion of many highway projects for years and even have caused some projects to be cancelled. One of the most famous examples is the section of interstate which was to be located between the French Quarter and the Mississippi River in New Orleans. This project was halted because of its aesthetic degradation to the historic French Quarter.[70]

Because of the extensive amount of land required by most interchanges, it is important that the interchange design engineer be included in the preliminary location study of the freeway in order to minimize the environmental impact of the interchange layout.

<u>Interchange Area Land Use</u>

Many studies have been conducted analyzing the impact of an interchange on adjacent land use.[71,72,73] The added accessibility and diverted traffic associated with an

interchange, make the land adjoining the interchange invaluable. Recent research has shown that land development is affected by the type of intersecting highway and the relative accessibility of each interchange quadrant, which is dependent on the type of interchange.[74,75] Additional factors are the traffic volumes on the freeway and the crossroad, the distance and direction to the nearest urban center and the population of the urban area.

Most studies show that highway-oriented development is the primary use.[76,77] However, a trend has developed, especially in suburban areas, to locate industrial parks, large apartment complexes and shopping centers in close proximity to an interchange. Accessibility has become one of the cornerstones of our society.

Land Use Controls

The literature makes little mention of land use controls as criteria in the interchange selection process. No references were made to existing zoning, comprehensive plans, access policies on the crossroad and subdivision regulations. However, the California Highway Department does recommend, as a part of the basic data required for interchange design, that data on existing and proposed land use be collected.[78]

Highway Design Manuals

The Highway Design Manuals of the following states discuss to some degree the interchange selection process

- Alabama
- California
- Colorado
- Florida
- Idaho
- Illinois
- Louisiana
- Massachusetts
- Michigan
- Missouri
- Montana
- Nevada
- New Mexico
- New York
- Oklahoma
- Oregon
- Pennsylvania
- South Dakota
- Texas
- Utah
- Virginia
- Washington
- Wisconsin

These two Canadian publications also include a section on the selection of interchange types:

Manual of Geometric Design Standards for Canadian Roads and Streets

Urban Highway Design Guide - Province of Alberta

The following states either have no design manual or make very little or no direct references to the design of interchanges:

- Alaska
- Arizona
- Connecticut
- Delaware
- Hawaii
- Indiana
- Iowa
- Kentucky
- Minnesota
- Missippippi
- Nebraska
- New Jersey
- North Carolina
- North Dakota
- Ohio
- Tennessee
- Vermont
- West Virginia
- Wyoming
- Kansas
- New Hampshire

No information could be obtained concerning the existence and/or content of highway design manuals in the following states:

Arkansas	Maryland
Georgia	Rhode Island
Maine	South Carolina

Evaluation of the Literature

The review of the literature was revealing from the standpoint of how little has been written about the interchange selection procedure. There apparently has been little effort to develop an evaluation methodology to assist in the selection of an interchange type. There also appears to be a tendency to give lip service to many non-quantifiable criteria because of the difficulties associated with evaluating such criteria.

Jack Leisch has probably done the most work in this area. His recent article[79] summarizes most of his previous work into a systems engineering approach for the determination of interchange types. In this author's opinion, this was the best reference on the interchange selection procedure found during the literature review. It contained an evaluation procedure based on a weighting technique for the comparison variables. Leisch's work served as a good starting point for this research.

CHAPTER 3: SCOPE, PROCEDURE AND METHODOLOGY

Scope

This research project concerned itself with the development of guidelines for the interchange selection process. Since the research was limited to the development of guidelines, the end product is not an exact procedure or set of standards, which, if followed, will result in the "best" interchange for the given situation; but rather an approach to interchange design based on the following three elements:

1. the development of a philosophy to interchange design
2. the development of evaluation criteria
3. the development of an evaluation methodology

The scope included the study of freeway-to-freeway interchanges (system interchanges) and freeway-to-local road interchanges (service interchanges) both in the rural and urban areas.

Procedure

Major input to this research came from personal interviews with several practicing highway design engineers. Before the decision was made as to which highway

departments to visit, the review of literature was completed and a list of questions was developed in order to make the interviews more profitable. It was also necessary to visit the Federal Highway Administration's Washington office in order to determine the state of the art of interchange design. Based on the review of literature and the state's geographic location to Purdue University, six state highway departments were selected for field trips:

California	Michigan
Indiana	Ohio
Illinois	Texas

Since the state highway departments of Indiana, Michigan and Ohio administer or perform most of their design work from the central office, it was only necessary to visit their central offices to obtain an accurate picture of their interchange design procedures. Ohio and Indiana almost exclusively use consultants while Michigan does its own interchange design.

In the states of Illinois, Texas and California, it was necessary not only to visit with central office personnel, but the personnel at lower levels in the district and resident engineer's offices. The State of Illinois uses consultants; however, the consultants work at the district level. The states of Texas and California do their own designs either at the district or resident engineer's level. The various district and resident

engineers offices that were visited in these three States are listed in Table 5. The questionnaire that was used in the interviewing process is included in Appendix A.

While visiting the Federal Highway Administration in Washington and the six highway departments, an exhaustive search was conducted in their respective library facilities to determine which state highway departments have highway design manuals and to what extent the existing design manuals discuss the interchange selection procedure.

For the remaining forty-four states, a shortened form of the original questionnaire was sent to the state highway design engineer or his equivalent. Thirty-four of the forty-four states responded to the questionnaire. Another form of the original questionnaire was sent to twenty-one highway design consultants located throughout the country; eleven responded. Copies of these two shortened questionnaires are also included in Appendix A along with a list of the state highway departments and consultants who responded to the request for information.

Methodology

Each practicing interchange design engineer seemed to have developed his own philosophy or approach to interchange design; but nowhere was there a summary of these empirically derived interchange design methodologies. Included in all of these individual approaches was a list

TABLE 5

DISTRICT AND RESIDENT ENGINEERS' OFFICES

VISITED DURING THE FIELD TRIPS

State	District or Resident Engineers Office	
Illinois	#2	Dixon
	#3	Ottawa
	#4	Peoria
	#6	Springfield
	#8	East St. Louis
	#9	Carbondale
	#10	Chicago
California	#4	San Francisco
	#7	Los Angeles
	#8	San Bernardino
	#10	Stockton
Texas		Austin District Office
		Austin Expressway Office (R.E.)
		Travis County Office, Austin (R.E.)
		Houston District Office
		Houston Urban Office

of criterion which the designer thought should be considered in the selection of an interchange type. The weight assigned to each of these criterion varied from individual to individual. Many of these factors were not quantifiable in terms of dollars and, therefore, not included in the traditional engineering economy analysis. The product of this research is a fusion of these many individual approaches to the selection of an interchange type into an evaluation methodology.

The evaluation methodology proposed in this research is simple and straight forward, necessary attributes if implementation of the methodology is to be expected. The interchange design engineer does not have the time to follow through an elaborate process or the trust in some of the so-called sophisticated mathematical approaches. He may use an evaluation technique if he feels that both professionals and the general public will understand and accept the results; and if it does not require too much time. Time is always critical in design, often allowing only a relatively quick analysis.

The proposed evaluation methodology is divided into four parts:

1. An analysis of the suggested evaluation criteria to determine which pertain,
2. The development of an "effectiveness profile",

3. The calculation of the initial cost for each alternative interchange design, and
4. The subjective comparison between the initial cost of each alternative interchange configuration and the results of the Effectiveness Profile.

The purpose of the evaluation methodology is to give the decision maker a tool to assist him in making the final decision as to the interchange configuration to design.

CHAPTER 4: INTERCHANGE DESIGN PHILOSOPHY

The design of an interchange is an art as well as a science. The designer not only needs the technical knowledge gained from books, he needs the experience of designing various interchange configurations. Through the combination of book learning and field experience, most interchange design engineers have developed their own interchange design philosophy. In an attempt to capture as many of these philosophies as possible, the following question was asked of the state highway design engineers and the practicing design consultants: "Do you have any unwritten policies on the type of interchange to use?" The results from the thirty-four highway department respondents are included in Table 6. The same question put to the eleven practicing design consultants resulted in the tabulation shown in Table 7.

Several conclusions can be drawn from these tables. Most design engineers claim they do not have any unwritten policies which govern their engineering judgment as to which type of interchange to design. Moreover, they also claim that each particular interchange problem should be attacked as an individual project and not stereotyped as to type. It

TABLE 6

POLICIES HELD BY HIGHWAY DEPARTMENTS

Policy	Number
1. No unwritten policies or "rules of thumb"	17
2. Use Diamonds wherever possible - simplicity	10
3. Each interchange design stands on its own merit	6
4. Use diamond interchanges in rural areas	4
5. Provide design needed to handle traffic	4
6. Two fully controlled access highways must be interchanged by a cloverleaf or directional (cloverleaf interchange with C-D road)	3
7. No left turn exits or entrances	2
8. Minimize weaving	1
9. Single entrances and exits	1
10. Exits should precede entrances	1
11. Use AASHO desirable ramp design speeds where possible	1
12. Use buttonhook ramps to two way frontage roads	1
13. Use free flow connections to one way frontage roads	1
14. Use the standard cloverleaf interchange wherever possible	1
15. Never use trumpet interchanges	1
16. Use partial cloverleaf interchanges in most urban situations	1
17. For a crossroad with full control of access do not use a left turn type of interchange	1

TABLE 7

POLICIES HELD BY CONSULTANTS

Policy	Number
1. The designer should not be restricted, he must keep an open mind	3
2. a "no" response	2
3. Avoid weaving if at all possible	1
4. Try to provide uniformity of entrances and exits	1
5. Use diamond wherever possible	1
6. Use Parclo interchanges as little as possible because of driver confusion and resulting accidents	1
7. Directionals should be used very little in urban areas because of cost and disruptive effect to adjoining property	1
8. Cloverleaf interchanges are usually precluded in urban areas because of site requirements	1
9. No left turn entrances or exits	1
10. No main line curves in the interchange area	1

is evident, however, that the diamond interchange is believed by many to meet the requirements placed on a local service interchange, both in urban and rural areas.

After the review of the literature, interviews with practicing interchange design engineers and the analysis of the questionnaires, several policies or principles became clear as basic requirements to achieve good interchange design. In addition to these basic or cardinal interchange design principles, several other more general or secondary interchange design principles emerged from the data.

Probably the most obvious conclusion resulting from the data collection phase is that there cannot be any rigid set of standards developed for the interchange selection process. Every engineer stressed the importance of individual design for each interchange. It was also apparent that some states follow this policy to a greater degree than do other states.

The purpose of developing an interchange design philosophy was not to establish a definite set of rules or steps for the interchange designer to follow; but, to remind the interchange designer of the many guidelines that have been developed by various design agencies through experience and that may be applicable in his given situation. All of the philosophies or principles cannot be applied in every design situation, but, as many as possible should be followed. The interchange design decisions require that

many factors be balanced. Different people react differently and, therefore, weigh factors accordingly. By the use of the proposed evaluation methodology, it is hoped that the designer will be forced to evaluate the importance of each of the several policies discussed in this research and incorporate them, as appropriate, in the design of interchanges.

Probably the most constraining force to the use of many of these principles is the constraint of economics. It is relatively easy to compare construction costs and right-of-way costs between interchange types. It is difficult, if not impossible, to measure the decrease or increase in "cost" because of smoother traffic operational characteristics, safer traffic conditions or a overall good traffic flow environment. If somehow, monetary values could be placed on these characteristics, it would be much easier to justify and implement many of these suggested interchange design principles.

The remainder of this chapter is divided into two segments. The first part lists the basic interchange design principles; those principles that are considered fundamental to the good design of any interchange. Each of the principles are discussed briefly in order to provide the reader with a clear explanation of what is meant by each of the principles. The second part of this chapter is a brief discussion of the secondary interchange design principles.

Basic Interchange Design Principles

These principles are fundamental to the good design of any interchange and should be thoroughly considered in every interchange design situation.

1. Minimize the Number of Weaving Sections
2. Use No Left Hand Entrances or Exits
3. Design for Flexibility - Design Flexibility and Operational Flexibility
4. The Crossroad is an Important Part of the Interchange
5. Design with Uniformity of On and Off-Ramp Configurations Along a Freeway
6. Simplicity in Design Should be Followed
7. Provide Adequately for All Possible Movements
8. Route Continuity Should be Followed
9. Provide Collector-Distributor Roads with All Cloverleaf Interchanges
10. Interchange types should be Selected Primarily on Traffic Requirements and Not on Costs
11. The Concepts of Lane Balance and Basic Number of Lanes Must be Maintained
12. Aesthetics and Community Impact Must be Considered.
13. Adequate Signing Must be a Consideration.
14. The Construction Scheduling for the Various Freeway Segments in the Completed System Must be Considered
15. The Spacing of Interchanges is Critical to Good Interchange Design

16. External Controls can Affect the Interchange Configuration
17. Safety Must Always be Considered
18. Interchange Configuration Should be a Consideration in the Initial Route Location Process

Some of these principles need further elaboration to understand why they are considered as fundamental to the design of any interchange. The order of these cardinal principles has no bearing on their relative importance; all of these principles are vital to good interchange design.

1. Minimize the Number of Weaving Sections

A weaving section is defined as a length of one way roadway accommodating both merging and diverging maneuvers and is inherent to a specific type of interchange - for example, a full cloverleaf - or is developed through the use of closely spaced interchanges as traffic volumes increase. Weaving sections may severely reduce speed and capacity and, on high speed-high volume sections, cause high accident rates and congestion. One reference suggested that the minimum distance between any entrance and the following exit on a freeway should be 1800 feet.[1] Another reference states that the minimum weaving length should be 1600 feet, with an additional 1000 feet provided for each lane crossed above the simple one lane weave movement.[2] Inherently included in the principle is the concept that exits should

precede entrances in interchanges, which removes the potential weaving problem and increases the capacity of the on-ramp maneuver by removing vehicles from the outside lane before injecting the on-ramp traffic.

2. Use No Left Hand Entrances or Exits

The general consensus of opinion of the design engineers is that left hand ramps are no good. They are usually unexpected to the driver and cause the following problems:

1. larger than normal speed differential between the entering traffic and the traffic in the fast left hand lane;
2. blind weaving maneuvers across one or more freeway lanes in an attempt to get to the right hand lane;
3. difficulties in signing; and
4. legal problems in many localities where trucks must be in the right hand lane by law.

If a freeway had all left hand ramps for a significant length, then some of the traffic flow problems caused by left hand ramps would be reduced: however, left hand ramps seem to be used only in isolated locations in an attempt to cut costs. From the standpoint of uniformity, simplicity and safety, left hand ramps have no place in interchange design.

3. Design for Flexibility - Design Flexibility and Operational Flexibility

"Flexibility is that special attribute of the highway system that will enable it to meet demands which will inevitably be made upon it but which today cannot be quantifiably predicted."[3] Just as control of access is now accepted in the design of freeways so should flexibility be recognized as essential to good interchange design.

Design flexibility is a design technique that does not preclude the possibility of future modifications to the present design in order to meet increased travel demands. Included under design flexibility would be the following procedures:

1. purchasing extra right-of-way for future expansion;
2. building spread diamonds with the thought that loop ramps could be added when left turns on the crossroad become extensive;
3. designing the cross structures wider for possible additional through freeway lanes; and
4. designing one-lane ramps with the possibility of expanding these ramps to two-lane ramps.

Operational flexibility implies a satisfactory manner of use for a range of traffic demands differing from those for which the facility was planned and designed. It could include such design elements as:

1. continuous frontage roads in congested areas which provide escape routes during periods of delay;
2. collector-distributor roads to remove weaving from the through lanes; and
3. auxiliary lanes preceding off-ramps, succeeding on-ramps or connecting successive ramps.

Another way of defining operational flexibility is to say that interchanges should always be designed with a margin of safety to compensate for any underestimating of travel demand. A good example of this is the situation when a two-lane ramp diverges from a six-lane freeway (three lanes in each direction). Normal practice would be to reduce the number of through lanes from three to two just beyond the two lane off ramp and then to add a through lane with the on-ramp. However, if the concept of operational flexibility is followed, the three through lanes would be carried through the interchange with an auxiliary lane added prior to the two lane off-ramp, for approximately 2500 feet. This also makes the off-ramp easier to sign.

4. <u>The Crossroad is an Important Part of the Interchange</u>

Due consideration must be given to the crossroad at every interchange location. When the two intersecting facilities are both freeways there does not seem to be any problem; however, when the crossroad is not an access

controlled facility many interchange design engineers feel that their responsibilities cease at the curb returns of the ramp terminals on the crossroad. Part of this feeling is due to the fact that the federal participation usually terminates at the curb returns.

It is important that a total systems approach be applied at each interchange location. This means that the crossroad must be considered as a part of the interchange for some distance along both approaches. From discussions with the practicing engineers, the final conclusion is that the interchange "zone of influence" on the crossroad should be taken to the first major intersection on both crossroad approaches to the interchange. This distance is required to disperse the disrupting effects caused by the freeway traffic merging and diverging with the local arterial traffic.

Also, the type of traffic operations on the crossroad must be considered when designing an interchange. Diamond interchanges fit better when the crossroad is already signalized. However, care must be taken not to space the diamond ramp terminals in such a way that a series of closely spaced signalized intersections develop which become difficult to efficiently operate. Many states have experienced problems on the crossroad when a free flow entrance ramp (loop ramp) emits traffic in the near vicinity

of a signalized intersection. The departing speeds from the free flow ramp and the weaving maneuvers which often result are not compatible with the traffic operation of the crossroad. Also, with a traffic signal near a free flow ramp terminal, many times the resulting queues at the traffic signal will back up onto the ramp, causing a hazardous situation.

With the proper design of the crossroad facility, many of the problems associated with wrong way maneuvers can be greatly reduced. Every crossroad should be channelized through the interchange area, and in most cases be wide enough to design left turning lanes for both directions of flow. Proper channelization design is considered a good way to minimize wrong way movements on interchange ramps.

Another design characteristic of the crossroad that is often neglected is the difficulty in properly signing the interchange on the crossroad approaches because of the land use and vehicular congestion which usually exist in urban and suburban environments. The lack of advance signing, poor sign visibility, roadside distractions and complex traffic flow patterns all hinder the motorist's performance; a fact which could result in wrong way maneuvers. The ultimate goal is to maintain on both roads the same level of service through the interchange area as there is approaching the interchange.

5. <u>Design with Uniformity of On and Off-Ramp Configurations Along a Freeway</u>

The systems approach to interchange design not only includes the crossroad but also the overall pattern of ramp terminals on the freeway facility. Uniformity would provide the driver with a common experience as he approaches each interchange. He would know if he exits prior to the cross structure or after the cross structure. Uniformity reduces the number of decisions required of the driver as he is travelling at high freeway speeds. It also makes it easier to sign the interchange.

The principle of uniformity includes the concept of one exit from the freeway prior to the cross structure. Some designers are strong believers of the one exit - one entrance policy for each interchange; however, some state highway departments have found it better to have two separate entrances to the freeway instead of a two-lane on-ramp. They feel that two-lane ramps are bad, in general; a two-lane on-ramp being worse than a two-lane off-ramp. In California this concept has been followed to the extent that some collector-distributor roads have two entrance points onto the freeway in order to have two small flow entrance points instead of one heavy flow entrance.

6. Simplicity in Design Must be Followed

Simplicity in design is closely related to uniformity of design. Simplicity means that driver confusion is kept to a minimum; the driver is faced with one decision point at a time; the signing is simple and clear, allowing for adequate time to make the proper decision. A synonym for simplicity of design is expectancy. Something as simple as making longitudinal construction joints to coincide with the proper usage of lanes helps to simplify operations in an interchange area. Also included in this principle is Leisch's idea of "anticipatory sight distance". Anticipatory sight distance means that the approaching driver can see an exit ramp far enough in advance that he can anticipate his departure from the freeway and aim his vehicle accordingly. Too often blind ramps and disappearing ramps, which have been designed into our freeways, result in a surprised driver and, therefore, a driver very susceptible to making an unexpected maneuver, which creates a high accident potential location.

7. Provide Adequately for All Possible Movements

Always provide for all interchange movements, especially with a service interchange. There is no excuse for not providing all of the movements except in very extreme situations. The lack of any one movement can cause confusion and result in wrong way maneuvers. In the case of

a system interchange, sometimes it seems logical to leave out one particular movement when the freeways double back on each other. In some cases this doubling back movement has been left out because of the extreme cost to provide such a low volume movement; however, it is sometimes possible, with adequate signing, to make this movement on a series of local streets. Another rationalization for leaving out ramp movements has been the fact that the traffic assignment has shown a desired turning volume of zero for the design year. It is probable that many visitors passing through an interchange are lost, perhaps as many as ten percent; in reality then there is no such thing as a zero assignment for any movement.

Isolated ramps should never be used. Such ramps invite wrong way maneuvers. Isolated ramps may be adequate for the familiar driver but to the unfamiliar driver, who should be the "design driver", isolated ramps are an invitation to trouble.

8. Route Continuity Should be Followed

There are two principles that must be considered simultaneously, route continuity and volume continuity. In most cases these two forms of continuity coincide, however once in a while they do not agree. It is better to follow the concept of route continuity in order to maintain a "balanced design" along a freeway route. Synonomous with the concept of route continuity is the concept of speed continuity.

Motorists seem to unconsciously associate speed continuity with route continuity and are, therefore, surprised when a low design speed section is encountered on a freeway. Long distance travelers do not expect to drive on low design speed sections between their origin and their destination on the freeway system. This is especially evident when a through route makes a ninety degree turn over a loop ramp. In most cases where this has been done, a serious accident problem has developed. Motorists just do not expect such low design speeds for a freeway through route.

9. Provide Collector-Distributor Roads with All Cloverleaf Interchanges

Some state highway departments flatly stated that they will not design any cloverleaf interchange without collector-distributor roads on both facilities in order to eliminate the inherent main line weaving problems with the cloverleaf interchange design. The concensus of the practicing engineers was that the only practical use of a cloverleaf interchange is for a system interchange in a low volume rural situation because a cloverleaf interchange is the lowest type of free flowing interchange. They feel that collector-distributor roads should become a basic design element of a cloverleaf interchange.

10. Interchanges Should be Selected Primarily on Traffic Requirements and not on Costs

Generally it was found that justification for an interchange configuration was based almost entirely on the operational characteristics of the various alternatives and very little on a cost comparison of the alternatives. It appeared that if two or more interchange configurations had the same operational characteristics then and only then was economics considered as a justification of one over the others. When the construction of freeways was in the infancy stage, cost comparisons were the only way to justify a particular interchange configuration. However, in the past fifteen years much knowledge has been gained about the operational characteristics of the various interchange types which has made it possible to give more weight to operations and less to cost.

"Interchanges are permanent installations and designs have too often been chosen on cost factors alone, resulting in an inadequate facility which in time must be changed".[4] Standards should never be cut in order to save money, it would be better to shorten the project or go to stage construction. Also, experience has shown that the difference in costs between acceptable and good standards is often a small percent of the total interchange cost.

11. <u>The Concepts of Lane Balance and Basic Number of Lanes Must be Coordinated</u>

Care should be taken that both of the concepts, lane balance and basic number of lanes, be analyzed in coordination. If lane balance is followed without giving proper consideration to the basic number of lanes, bottlenecks can develop especially where a two lane ramp departs from the freeway. The recommended approach is first to consider the basic number of lanes and then to consider the proper lane balance.

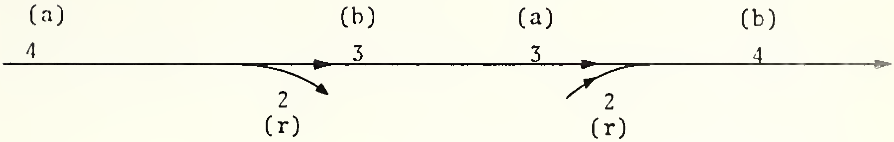
A Northwestern University publication[5] defines lane balance as "The number of lanes on a freeway beyond the point of mergence should be equal to or greater than the number of lanes on the freeway in advance of the point of mergence, plus the number of lanes on the entrance ramp, minus one. The number of lanes on a freeway in advance of the point of divergence should be equal to or greater than the number of lanes on the freeway beyond the point of divergence, plus the number of lanes on the exit ramp, minus one." Since many designers use minimum standards instead of desirable standards, a common lane drop problem has resulted in interchange areas where a two lane off ramp is present. Figure 5 illustrates the typical lane drop bottleneck which meets the lane balance criteria but violates the basic number of lanes concept. The recommended lane design is also shown in Figure 5. The basic four through lanes are continued through the interchange area and a 2500 foot

a) basic number of lanes = 4

r = number of ramp lanes

a = number of through lanes up stream from a ramp

b = number of through lanes down stream from a ramp



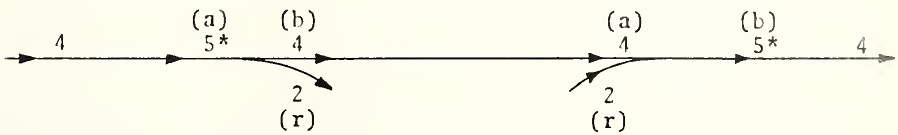
$a \geq b + r - 1$

$4 \geq 3 + 2 - 1$

$b \geq a + r - 1$

$4 \geq 3 + 2 - 1$

b) basic number of lanes = 4



$a \geq b + r - 1$

$5 \geq 4 + 2 - 1$

$b \geq a + r - 1$

$5 \geq 4 + 2 - 1$

*one lane an auxiliary lane

FIGURE 5 LANE BALANCE CONCEPT

auxiliary lane is added prior to the two-lane off-ramp and after the two-lane on-ramp. In Figure 5 both concepts of lane balance and basic number of lanes are fulfilled. The only time the equality sign can be a factor in the lane balance analysis is when a major bifurcation exists or two auxiliary lanes are added prior to or after the respective ramp maneuver although this latter situation rarely exists. The important thing to remember is that the basic number of lanes should not be sacrificed in an attempt to follow the concept of lane balance.

12. Aesthetics and Community Impact Must be Considered

Because of the dynamic impact an interchange has on the development of adjacent land, the interchange design engineer must look at a number of non-engineering variables when considering the type of interchange to design. The design engineer should look at the existing zoning and land use to determine the existing site conditions. This can be done by an on-site inspection supplemented by airphotos and an up to date zoning map of the area. Also, the design engineer should look at the proposed land use plan to get a better idea of what type of land use and, therefore, traffic generation patterns will probably develop in the interchange zone of influence. If a comprehensive plan exists, this could be a good source of information. An engineer should also look at the effectiveness of the land use controls,

such as the access control policy of the highway department or local area, to better understand the possible development of the land adjacent to the interchange.

Certain interchange configurations provide more accessibility to the crossroad in general and to certain quadrants in particular. For example, it may be better to stop all traffic at the ramp terminal through the use of traffic signals in order to provide the necessary gaps in the crossroad traffic to allow ramp traffic to weave across the crossroad to turn into an access point. The traffic flow characteristics of a free flow ramp may not afford this opportunity to the departing freeway driver, thus resulting in congestion and hazardous maneuvers on the crossroad between the ramp terminal and the access point.

The consensus of opinion of the engineers interviewed was that aesthetics must be considered, but no one knew how to measure aesthetic value. The following quotes were obtained during the field interviews and serve as a summary of what aesthetic quality means to practicing interchange design engineers.

1. "Provide wider structures.
2. Use open-ended bridges.
3. Contour grade the interchange area.
4. Plant trees, bushes and shrubs in the interchange area, however, be careful as not to build in a visual obstruction to the motorist.

5. Aesthetics is linked to economics: it is not that the engineer is more aesthetically oriented now than in the past; it is that the public is more willing to spend the money for aesthetics. In the past the Federal Highway Administration would not have approved the design plans currently accepted because of the additional cost associated with aesthetic considerations.
6. Aesthetics is the coordination of horizontal and vertical alignment.
7. There is no way of measuring the aesthetic value of an interchange design. However, there is a way of evaluating aesthetics through the use of models. Models help and do not cost very much. It is possible to "get a feel" for the spatial relationship and view from several ramps. It is also possible to get a feeling for scale shapes. Artists renderings help, especially in selling the project to the public.
8. Aesthetic values have not entered so much in the basic design of an interchange but in the construction features within the basic design; for example, stone facing.
9. Highway departments are no longer restricted on first cost. They can give attention to aesthetics. A lot of money does not have to be spent to have

something aesthetic. "Icing on the cake" appearance is bad.

10. Symmetrical interchanges are pleasing.
11. Put the crossroad over the freeway.
12. Landscape the project (some states landscape after the interchange is built; others prefer to involve landscape architects in the initial design of the interchange).
13. If operations are the same, then consider aesthetics. Operations should never be sacrificed for aesthetics.
14. Depress the freeway approximately ten feet. This eliminates the hump effect on the crossroad."

13. <u>Adequate Signing Must be a Consideration</u>

The basic problems with signing are 1) placing too much information or confusing information on signs; 2) locating signs too close together; and 3) involving the signing engineer after the final interchange configuration has been selected. The signing engineers should either be trained in human factors engineering or be able to communicate with the human factors specialists. The average driver can only comprehend a limited amount of information from a sign as he passes at freeway speeds. The placement of words, the type and size of letters, the directional message (route number; north, south, east, or west designation; names of cities or places, etc.) and the colors used, all affect the legibility

and understandability of a sign. The more complex the interchange design, the more important role signing plays.

The field interviews showed that the persons in charge of signing have gotten into the habit of signing after the fact. Either because of a lack of personnel or the internal structure of the highway department, the signing engineer, in many cases, does not do an acceptable job of review prior to the establishment of the interchange configuration. The rationalization for this practice is that an interchange designer must know signing before he can do an adequate job. There are many examples of good interchange signing;however, there are too many examples which look like the interchange was designed, constructed and then someone was told to sign it and make it work.

14. <u>The Construction Schedule for the Various Freeway Segments in the Completed System Must be Considered</u>

Since traffic volumes and flow patterns which are used to design an interchange are always based on the completed freeway network, many times problems result at interchanges because of the time lag associated with building different parts of the freeway system. It would be economically feasible many times to design an interchange to handle a certain traffic flow pattern for the first ten to twenty years of its life, realizing that the traffic flow pattern would change if and when the freeway system is completed.

In many locations, there are links in the proposed total freeway system which are very controversial and probably never will be built; yet adjacent links of freeway and, therefore interchanges, are designed on a traffic flow pattern based on the completed system.

15. <u>The Spacing of Interchanges is Critical to Good Interchange Design</u>

This principle is especially critical in urban areas. As a general rule, anytime successive ramps have to be connected through the use of an auxiliary lane, the interchanges are too closely spaced. "In urban areas the spacing of interchanges on freeways should be rarely less than 2/3 of a mile or 3600 feet. (900 foot ramp plus 1800 foot weaving section plus 900 foot ramp). Preferably, the minimum should be upwards of 4000 to 5000 feet. As an average, a minimum spacing of one mile is considered appropriate in urban areas. In outlying and rural areas, interchange spacing is more approximately set at one and one-half to two miles."[6] Sometimes it is possible to obtain a longer distance between ramps through the use of partial cloverleaf interchanges and braided ramps, but uniformity in ramp patterns should be maintained.

16. External Controls Can Influence the Interchange Configuration

Many times existing land use, topography and/or man made obstructions directly influence the possible interchange configuration. The presence of a railroad or a river paralleling the crossroad usually results in a partial clover-leaf type interchange (Parclo A-B), which has all four ramps on the same side of the crossroad. Ramp design in a particular quadrant is influenced greatly by the presence of a cemetery, school, park and any other public land use. The existence of these latter land uses has been the main reason in the past for the use of the Parclo type inter-changes.

17. Safety Must Always be Considered

Some of the characteristics of a safe interchange design are:[7]

1. sufficient capacity for smooth continuous traffic flow;
2. sufficient sight distance so drivers will have enough time to make one decision at a time;
3. high horizontal and vertical ramp and crossroad alignment standards;
4. no surprises to the driver - lane drops, isolated left hand ramp, etc.; and
5. clear roadside with good grading and with pier and bridge columns set back.

The crossroad and the crossroad ramp terminals must always be channelized to discourage wrong way movements. Channelization has proven to be the best deterent to the wrong way motorist.

Much has been written about safe gore area design or the elimination of obstructions from the gore. For emphasis it still bears repeating. Keep gore areas as clear as possible. If this is impossible, use traffic attenuation devices, breakaway sign supports and breakaway light standards. Basically, all of the previous principles have safety as one of the reasons for their existence; safety is directly related to good operational characteristics.

18. Possible Interchange Configuraions Should be a Consideration in the Initial Route Location Process

In rural areas this principle is not as important as in urban areas. In rural areas the corridor can be selected with only the general feasibility of an interchange determined at a particular crossroad. However, in urban areas this same approach cannot be followed. Several of the practicing engineers stated that interchanges control the location of a route in an urban area to the extent that first the interchanges are located and then the connecting freeway links are designed between these interchange locations. The emergence of curvilinear design has helped to inaugurate this location technique, along with the large

amount of land required for an interchange and the high cost of land.

It is generally felt that the earlier the interchange design engineer is involved in the preliminary planning, location and design of the freeway facility the better the interchanges will fit the overall environment. Jack Leisch[8] has a term for this approach to interchange design; he calls it "preliminary functional design."

Secondary Interchange Design Principles

Through the course of this research project certain secondary interchange design principles became obvious. These principles could be considered "rules of thumb" for the selection of an interchange configuration and are discussed in the following paragraphs.

Use diamond interchanges wherever possible for service interchanges both in rural and urban areas. Modifications of the general type diamond interchange should be used where applicable; for example, spread diamonds where the need might occur to put in a loop ramp in the future; split diamonds to a one-way urban street network, braided diamond ramps where applicable on closely spaced interchanges.

Left turning movements control the type of interchange. The designer should concern himself first with the manner in which he handles the left turning desires at the interchange site. All right hand movements are normally handled on direct ramps.

Freeway to freeway interchanges must be one of two types because of the free flow requirement for system interchanges:

1. A cloverleaf interchange with C-D roads on both facilities when both facilities are low volume roads.
2. Directional interchange for high volume facilities.

Avoid standard trumpet interchange unless it is physically impossible for the discontinued highway to be extended. Case histories have shown that in almost all cases the desire to extend the truncated leg of a trumpet interchange has developed.

For local service interchanges it is desirable to use a Parclo A-4 quadrant interchange when it becomes necessary to remove left turning maneuvers from the crossroad. Some state highway departments have started to use the parclo A-4 type of interchange almost exclusively on some routes. They like the two entrance-one exit feature of this configuration, plus the fact that the loop ramp serves as on on-ramp to the freeway while removing the left turning traffic from the crossroad.

A major bifurcation or fork is not a left hand ramp. That is to say that a point of major divergence or convergence is not designed similarly to a left hand on ramp or left hand off ramp. Many design agencies do not accept left hand ramps, however they do appreciate the difference between

left hand ramps and major points of bifurcation.

It is usually preferable to have the crossroad (minor facility) elevated over the main line (major facility). There are several reasons for this; one of which is the better sight distances associated with an off-ramp on an upgrade; another is the operational advantages of having the off-ramp from a freeway on an upgrade and the on-ramp to a freeway on a downgrade. The respective grades help to decelerate and accelerate vehicles depending on their purpose of operation.

A distinction should be made between the two types of lane drops; a basic lane drop and an auxiliary lane drop. Auxiliary lanes are dropped at off ramps of either system interchanges or service interchanges. Basic lane drops do not occur as frequently and should never be located at a service interchange. Basic lane drops occur when the basic number of lanes is reduced which is usually based on a significant reduction in through traffic. Some states recommend that basic lane drops be located at a system interchange while other states believe this type of lane drop should be placed at least 2500 feet past an interchange at a 50:1 to 70:1 taper. The lane drops should be on the right hand side, except where a wide median exists for possible future widening of the freeway. Motorists on the right are use to turmoil and change; they are more alert to the signing required for a lane drop. The left lane driver is

the through, long distance driver who expects to drive straight ahead without any disturbances.

The combination of the basic interchange design principles and the secondary interchange design principles form the interchange design philosophy developed in this research. If this design philosophy was used as guidelines, many of the existing operational problems associated with interchanges could be avoided in the future. When one has reviewed the interchange design philosophy, the next step is to develop a list of evaluation criteria which can be used to evaluate alternative interchange configurations. The evaluation criteria are a manifestation of the interchange design philosophy. They are the means through which the interchange design philosophy is applied to the interchange configuration selection process.

CHAPTER 5: DISCUSSION OF INTERCHANGE EVALUATION CRITERIA

Existing Interchange Evaluation Criteria

The type of grade separation, over or under, and the type of interchange and its design are influenced by many factors. Speed, volume, composition of traffic to be served, number of intersecting legs, standards and arrangement of local streets, topography, right-of-way controls, local planning values, proximity of adjacent interchanges, community impact, and cost are some of the criteria which must be considered when selecting an interchange configuration for a particular design situation.

Lists of criteria which designers have considered as appropriate for determining an acceptable interchange configuration were discussed in the literature review. To expand the data and to determine which criteria are actually used in the selection of an interchange configuration, the questionnaires which were sent to the state highway departments and to the highway design consultants contained the following question: "What are the criteria that you use to determine the type of interchange to design?" Table 8 shows the summary of the thirty-four responses from the state highway departments. Table 9 summarizes the eleven responses from the highway design consultants.

Table 8

Highway Departments' Design Criteria

		No. of Times Included out of 34 Responses
1.	Turning volumes	17
2.	Terrain conditions	16
3.	R.O.W. requirements	14
4.	Traffic volumes (demand)	13
5.	Economics of construction	13
6.	Functional design of both roadways	8
7.	Crossroad type	7
8.	Design speed	5
9.	Land use, culture, land value	5
10.	Capacity requirements	4
11.	Proximity of other interchanges	4
12.	Site controls	3
13.	Through volumes	2
14.	Type of access control	2
15.	Local planning	2
16.	Traffic service	2
17.	Stage construction	2

Others Mentioned Once

18. Blue Book (pages 603-630)
19. Simplicity
20. Freeway level of service
21. Crossroad level of service
22. Ramp intersection volumes & capacity
23. Special conditions of roadway alignment
24. Site distance considerations
25. Weaving sections
26. Route continuity
27. Signing requirements

Table 8 (Continued)

28. Grades on freeway or crossroad
29. Design designation
30. Character & composition of traffic
31. Number of legs
32. Eliminate a bottleneck
33. Accident experience
34. Environmental & social impact
35. Safety & ease of driving

Table 9

Consultants' Design Criteria

		No. of Times Included Out of 11 Responses
1.	Topography (terrain & soils)	8
2.	Availability & cost of R.O.W.	8
3.	Costs (construction)	7
4.	Traffic volumes	6
5.	Turning volumes	6
6.	Present & future land use, customs, culture	6
7.	Type & class of intersecting roadway	3
8.	Through volumes	2
9.	Aesthetics	2
10.	Cost-benefit comparison	2
11.	Geometry for allowable design speed	2
12.	Environmental impact	1
13.	Client's requirements	1
14.	Dislocation aspect	1
15.	System requirements	1
16.	Level of service	1

In the questionnaires the designers were also asked to list the advantages and disadvantages of the various types of interchanges. This information was expanded through comments made during the field interviews and from printed guidelines of some state highway departments and individual interchange designers. In Appendix B is a composite listing of the advantages and disadvantages of the interchange configurations listed in Table 10.

Recommended Interchange Evaluation Criteria

The interchange evaluation criteria are divided into two general categories: (1) Operational and Design Factors and (2) Community Disruption Factors. Under each general category are several factors which, themselves, are further subdivided as shown in Table 11, in an effort to clarify what the factor represents. This table is by no means all inclusive; in fact, it is intended to be an open-ended list, allowing for the individual characteristics of a particular site to be included in the evaluation analysis. For example, a particular interchange location may infringe on an historical site which is important to the community. The impact of the alternate interchange configurations on this historical site should be included in the evaluation analysis.

The open-endedness of the list of interchange design criteria is a necessity. There is no way that all of the

Table 10

Interchange Configurations Analyzed

1. Tight Diamond
2. Spread Diamond
3. Diamond with Couplets
4. Split Diamond
5. Tri-level Diamond
6. Diamonds with U Turn Structures
7. Diamonds with Left Turn Structures
8. Parclo A
9. Parclo A-4
10. Parclo B
11. Parclo B-4
12. Parclo A-B
13. Full Cloverleaf
14. Trumpet A
15. Trumpet B
16. Directional T or Y
17. Four Quadrant Directional

Table 11

Interchange Design Criteria

I. OPERATIONAL AND DESIGN FACTORS

Factors

A. Level of service continuity between the main line and the ramps

B. Level of service continuity on the crossroad through the interchange area

C. Safety
   1. Uniformity of flow
   2. Accident potential

D. Uniformity
   1. On and off-ramp design
   2. Route continuity
   3. Signing

E. Flexibility
   1. Basic number of lanes
   2. Lane balance
   3. Stage construction
   4. Maintenance of traffic during construction

F. Number and length of weaving sections

G. Others-depending on the design situation and the designer's experience

II. COMMUNITY DISRUPTION FACTORS

Factors

A. Number of acres taken outside of the main-line right-of-way

B. Number of families relocated

C. Number of commercial establishments relocated

D. Number of tax dollars removed from the tax rolls

E. Number of local streets closed

F. Taking of a particular parcel of land
   1. Church
   2. School
   3. Historical landmark
   4. Public land
   5. Other

G. Lack of access to adjacent property

H. Others-depending on the design situation, designer's experience and community feelings

possible evaluation criteria could be listed. Any interchange location could have its own peculiar characteristic which should be included in the evaluation procedure. Also, as more research is conducted, more knowledge will be accumulated on the recommended criteria which could change their relative importance. For example, to date not much is known about the accident potential of each interchange element, except for the work done by Cirillo, Dietz and Beatty on the Interstate System.[1] During the field interviews, it was learned that several state highway departments have recently collected, but not analyzed, accident data referenced to interchange type and types of ramps. When this information becomes known the accident potential of a particular interchange configuration can be more objectively evaluated.

Operational and Design Factors

There are, however, certain criteria which should always be included in the evaluation of alternate interchange configurations. Any interchange design must meet a minimum operational level to be acceptable. The minimum operational level proposed in this research is a design which fulfills the first six items listed under the operational and design factors. From a traffic operational point of view, an acceptable interchange configuration would have the following characteristics:

Level of service continuity between the through lanes and the ramps

An interchange must be able to handle the traffic demands. Level of service continuity is selected as the evaluation criterion to reflect the traffic handling capabilities of an interchange configuration because the term, level of service, includes a volume to capacity relationship and an indication of speed. Ideally, all of the interchange elements should have the same level of service throughout the interchange area.

Level of service continuity on the crossroad

The crossroad level of service in the interchange area should be equal to or greater than the level of service on the two crossroad approaches leading to the interchange area. All crossroads should be divided through the interchange area. If traffic signals are required, a check should be made to see if the signals fit into the overall traffic operations on the crossroad. Signing on the crossroad should be given proper consideration.

Uniform traffic flow pattern

This characteristic is directly related to safety. The interchange design should not force abrupt changes in travel speed. A speed profile of traffic flow through an interchange would indicate locations where accidents could occur if the driver is not alert.

<u>No design situations which have a high accident potential</u>

This characteristic is related to a uniform traffic flow pattern. It is believed that in the near future there could be sufficient data available from several state highway departments to supplement the work done by Cirillo, Dietz and Beatty to make some firm statements concerning the relationships between accidents and the interchange configuration. Some designers already have some strong sentiments in this area.

<u>All right hand ramps - exits prior to the cross-structure</u>

If at all possible, this characteristic should be followed. Why invite operational problems! By giving the driver what he expects, a safer condition results. Left hand ramps should never be built: points of major divergence or convergence are not left hand ramps. Loop off-ramps from the freeway should be avoided. It is operationally better to have a loop ramp serve as an on-ramp to the freeway.

<u>Route continuity</u>

Route continuity can also be expressed as speed continuity. Motorists expect a consistent high design speed on the entire length of a through route. The design speed differential between the main lines and an interchange ramp should be equal to or less than 0.3 of the main line design speed.[2] The larger the design speed differential the greater is the potential for an accident.

In certain situations it may be more appropriate to renumber the routes to preserve route continuity.

Signable design

If an interchange cannot be signed properly, it will not operate efficiently. Signing should never be after the fact. In complicated situations, signing must be considered during the development of the alternative interchange configurations.

One driver decision point at a time

This design characteristic is directly related to signing and human factors engineering. The motorist can only absorb so much information in a given period of time. If motorists are forced to make more than one decision at a time, the potential for erratic movements, unexpected maneuvers and, therefore, accidents greatly increase.

Coordination of the concepts of lane balance and basic number of lanes

By following the concepts of lane balance and basic number of lanes, certain bottlenecks can be avoided in the design of interchanges. It is recommended that the concept of basic number of lanes be followed first and then the concept of lane balance applied. This will require the use of auxiliary lanes, but it will prevent the common lane drop problem through an interchange area.

Possibility of stage construction

The possibility of stage construction, if applicable, should be considered. "In some cases an interchange is constructed in stages to fit an overall construction schedule of an arterial highway, to accommodate future area changes, to economically provide for present or immediate future traffic, or to keep construction costs within available funds. Selection of an interchange type might be affected by the need for stage construction, requiring examination of the first stage and the feasibility of constructing later stages with due consideration given to the maintenance of traffic and to operation during each stage. These considerations are particularly pertinent at directional or multileg interchanges. Where feasible, right-of-way for future development should be acquired during the initial stage."[3]

Maintenance of traffic during construction

"The selection of an interchange type may be influenced by the degree to which traffic must be maintained during construction. Sometimes a plan that appears desirable cannot be used because the existing traffic cannot be served during the construction period. ... For each interchange design, the plan for maintenance of traffic during construction should be developed concurrently with the design and checked for practicability, in particular the capacity to accommodate the peak-hour traffic volumes."[4]

Minimum number of weaving sections: zero if possible

Any kind of weaving section is bad; therefore, the fewer weaving sections, the more attractive the interchange design. Sometimes weaving sections cannot be avoided. In these cases the weaving sections should be as long as possible and separated from the through lanes by a collector-distributor road.

The designer may have a particular measure or measures which he has used in the past as operational and design criteria for the selection of an interchange configuration. The following are some of these additional criteria found through this research:

1. Travel time
2. Travel distance
3. Radius of curvature
4. Ramp grades
5. Topography
6. Soil conditions
7. Drainage
8. Spacing of interchanges
9. Design speed
10. Composition of traffic
11. Operating costs - running costs (fuel, tires, oil, maintenance)
12. Level of service

Community Disruption Factors

The community disruption factors should be individualized for each interchange design; so no set of criteria is recommended as a minimum measure of the impact upon the community from the various alternative interchange configurations. The objective is to minimize the detrimental community impact while maximizing the traffic operational capabilities of the interchange. Trade-offs between these two dichotomous interchange consequences are always present, which help to justify the form of evaluation methodology developed later in this research. Table 11 contains several of the more prevalent community disruption factors. Additional factors include noise and air pollution, local street connectors, landscaping opportunities, land development opportunities, local planning values, barrier effects and aesthetics.

These lists of operational and design factors and community disruption factors are intended to be open-ended because it is impossible to include in this report all of the factors which could influence the selection of an interchange configuration. The designer should anticipate the evaluation criteria considered important by the public and include these in the evaluation process. The important thing is to include the factors or evaluation criteria which affect the possible interchange type. The selection of a set of evaluation criteria based the interchange design

philosophy is the all-important first step in the evaluation methodology proposed in this research. Without a set of evaluation criteria as a foundation to measure the <u>differences</u> between the alternative interchange configurations, the proposed evaluation methodology is weak at best.

CHAPTER 6: EVALUATION METHODOLOGY

Interchange Selection Process

The main goal of this research was to develop an evaluation methodology that would assist the practicing design engineers to select an interchange configuration for a particular location. The total decision-making process recommended to select an interchange type is illustrated in Figure 6. This chart shows that the interchange design engineer should be involved not only in the route location study for a new facility but also in the planning study for the rehabilitation of an existing facility. The interchange design engineer can provide valuable inputs into both of these preliminary highway design phases by evaluating the feasibility of the interchange locations and developing preliminary interchange types for these locations. The involvement of the interchange design engineer at these stages will help to minimize the situations where an adequate interchange cannot be built because of predetermined constraints.

Once the determination is made that an interchange is needed, the first step is to determine if a system interchange or a service interchange is required. A system interchange must have all free flowing ramp terminals for the quick transfer of traffic from one freeway to another.

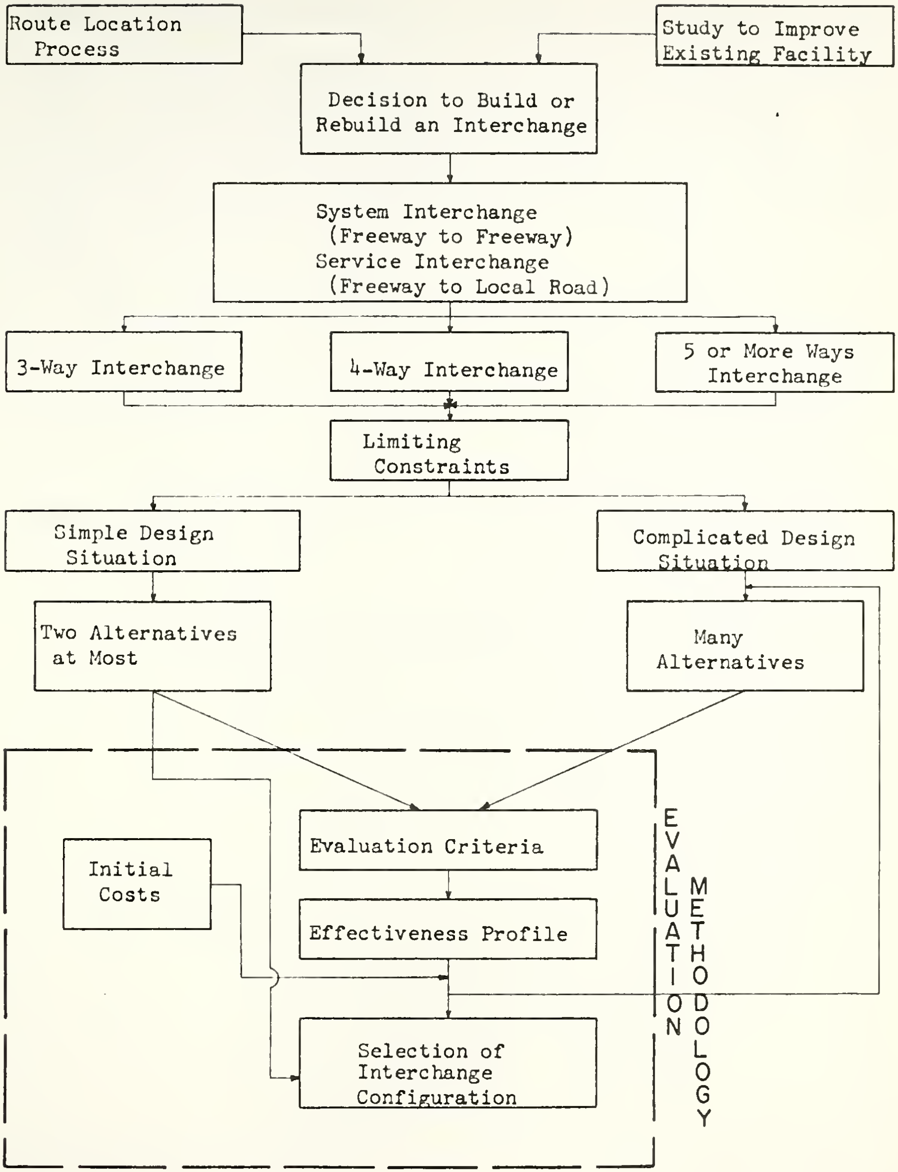


FIGURE 6 INTERCHANGE SELECTION PROCESS

Usually a service interchange has stop-controlled or signal controlled ramp terminals on the crossroad; but in certain areas, free flow ramp terminals may also be desirable. This division into either a system interchange or a service interchange reduces the set of possible interchanges that can be used in any given location.

The number of possible interchanges is still further reduced by classifying the desired interchange by the number of approach legs or streets: three-way; four-way; and five or more ways. The following list contains the interchange types which are applicable, based on the number of approach legs and the classification of the crossroad.

I. Three-way interchange (three approach roads)
   A. System Interchange
      1. Directional "T" or "Y"
      2. Trumpet A
      3. Trumpet B
   B. Service Interchange
      1. Directional "T" or "Y"
      2. Trumpet A
      3. Trumpet B
      4. Half Diamond
      5. Hybrids*

II. Four-way interchange (four approach roads)
   A. System Interchange
      1. Directional without loop ramps
      2. Directional with loop ramps
      3. Cloverleaf with C-D roads
   B. Service Interchange
      1. Directional with loop ramps
      2. Cloverleaf with C-D roads
      3. Parclo A-4
      4. Parclo A
      5. Parclo B-4
      6. Parclo B
      7. Parclo A-B
      8. Diamond with its many variations
      9. Hybrids*

III. Five or more way interchange (five or more approach roads)
   A. System Interchange
      1. Directional without loop ramps
      2. Directional with loop ramps
      3. Hybrids*(local ramps within a system interchange)
   B. Service Interchange
      1. Directional with loop ramps
      2. Rotary**
      3. Hybrids*

* Hybrids are interchange configurations which do not exactly fit any of the standard interchange configurations discussed so far in this research. Hybrids are modifications of the basic types of interchanges; the modifications are made to meet existing constraints.

**Rotary interchanges are not discussed in this research. Rotary interchanges should not be used in this country because of the operational problems associated with their built-in weaving maneuvers.

After narrowing the population of possible interchange types by the functional classification of the interchanging facilities and the number of approach roads, the designer should then determine if the design location has any limiting constraints on the interchange configuration. The existing land use in one quadrant may force the designer to completely avoid that quadrant when laying out the alternative interchange designs. For example, parks, schools and other public land are bypassed, if possible. The presence of frontage roads also limits the type of interchange. With a two-way frontage road system, partial interchanges are developed through the use of buttonhook ramps.†

†There are many disadvantages associated with buttonhook ramps. They are usually the "second best" solution, difficult to sign, induce wrong way movements when ramps are isolated, and require low design speeds. Buttonhook ramps should be avoided if possible.

Likewise, slip ramps are appropriate to connect the freeway to a one-way frontage road network. Interchanges with loop ramps are not readily adaptable to a frontage road system. The presence of a natural or man-made obstruction greatly influences the type of interchange. A river or railroad paralleling the crossroad can force all of the ramps to be located in two quadrants on the same side of the crossroad.

The next step is to determine if the particular design problem under study is a simple design situation or a complicated design situation. A simple design situation would require only one or possibly two alternative interchange designs. Even with a simple or clear cut design location it is recommended that two alternatives be developed and compared. An example of a simple design situation is a service interchange between an interstate route and a low volume secondary state highway where access is needed because of the long distance between adjacent interchanges. In this case, a diamond interchange would probably be designed. Most interchange designers would find it difficult to justify the time and expense of developing another alternative interchange configuration; and would consider it a waste of effort to use any detailed evaluation methodology. The interchange design engineer is encouraged, however, to check over the list of evaluation criteria to make sure the design situation is truly simple.

Several alternative interchange designs are developed when a complicated design situation is encountered. The number of alternatives usually varies from two to about ten, depending on the complexity of the design problem. The major obstacles involved in interchange design are in urban areas where development has already occurred and the impact on the environment,or the surrounding land, is felt the most. It is also in the urban areas where some of the early freeways are becoming obsolete and in need of rehabilitation. These highly congested routes have become corridors of high land development because of the accessibility afforded by these freeways. To correct the substandard acceleration and deceleration lanes, the closely spaced interchanges and the congested ramp movements, serious trade-offs have to be made between the community disruption factors and the traffic operational factors. The following evaluation methodology is proposed to compare these two dichotomous set of factors.

Evaluation Methodology

The evaluation methodology has the following segments:

1. The interchange design engineer should scrutinize the given list of evaluation criteria to determine which are pertinent to the design situation under study and which factors should be added.
2. The interchange design engineer should develop the initial cost for each alternative interchange

design. The initial cost should include

a. construction costs

b. right-of-way costs

c. relocation costs

3. The interchange design engineer should develop an Effectiveness Profile for each alternative interchange design.
4. The interchange design engineer should compare the initial cost of each alternative design to it's Effectiveness Profile and select the most cost effective interchange configuration. If the interchange design engineer doing the work cannot make the final decision on the interchange type then he should present the initial cost information and the Effectiveness Profile data to the decision maker.

Scrutinize the List of Evaluation Criteria

There are so many criterion which should be considered to some degree in selecting an interchange type that it is easy to overlook some. In Chapter Five there is a list of evaluation criterion that should be considered in the design of every interchange. These basic criteria are measures of the traffic operational capabilities of the interchange designs. If certain minimum traffic operational constraints are not met, there is no reason to further consider that interchange configuration.

Also in Chapter Five community disruption factors and other operational and design factors which have been used by design engineers in the evaluation of interchange types are listed. These lists are not intended to be all-inclusive, but rather a check list to ensure that the interchange designer has at least been made aware of these criteria. Some of the criteria will not be pertinent and, therefore, just passed over. However, the designer should make the judgment that a specific criterion is not applicable.

Evaluation criteria which measure the differences between the alternative designs should be selected. For example, it is recommended in Chapter Five that the level of service continuity between the main line and the ramps be one criterion always used in the selection of an interchange type. However, if all of the alternative designs are to have the same level of service throughout the interchange area, then this criterion need NOT be used in the evaluation methodology because it adds nothing. The selection of the evaluation criteria is fundamental to the proposed evaluation methodology; the evaluation criteria are the foundation upon which the comparisons between alternative interchange designs are made.

Develop the Initial Cost for Each Alternative Interchange Design

The initial cost of each alternative interchange design is selected as the cost figure to use in the evaluation

methodology, because it is easily obtainable and does not include some of the uncertainties associated with calculating road user costs. Included in the initial cost are the following items:

1. construction costs
2. right-of-way costs
3. relocation costs
    a. utilities
    b. families and businesses

Road user costs are not included in the determination of the cost of each alternative design because of the problems associated with calculating dollar values. Arriving at a value for time, the accumulation of small increments of time and the uncertainty associated with the monetary value of a fatality are some of these questionable areas. It is also felt that the road user costs would not be significantly different for the alternative interchange configurations.

If the designer feels that some measure of road user costs should be included in the evaluation process, he could always include it as an evaluation criterion. For example, the present worth of operating cost could be included in the analysis as a measure of the effectiveness of the alternative designs: the lower the operating cost then the more attractive will be the alternative design. The designer should make an honest attempt, however, to accurately determine the operating cost. He should not take the average

of the existing annual traffic and the projected annual traffic as the yearly traffic over the life of the project and apply the fuel, oil, maintenance, etc. factors. Operating costs not only vary over the duration of the project and the increase in traffic but also by the hour of the day.

Maintenance costs are not included because again it was felt that there would be no significant difference between the maintenance costs of the alternative configurations.

Development of an Effectiveness Profile

A technique is needed to compare the impact of the alternative interchange designs based on qualifiable as well as quantifiable criteria. There are several approaches that this evaluation procedure could take. It can simply be a rote process, similar to the interchange design table found in one of state highway design manuals. This technique of interchange configuration selection leaves nothing to the design engineer's imagination or ingenuity. The designer simply goes to a predeveloped table or chart and pulls off an acceptable interchange configuration.

One form of evaluation methodology applies economic measures such as the benefit cost ratio, rate of return, and net present worth. These techniques are primarily based on 1) first costs such as cost of construction and right-of-way costs, and 2) on motor vehicle operating costs,

such as costs associated with accidents, delays, and travel time costs. The alternative with the "best" ratio or economic index is the selected interchange configuration.

Another technique, a form of which is applied by Leisch,[1] uses a point weighting scheme, similar to the sufficiency rating method of evaluating highway pavements, to determine the best interchange configuration. The alternative with the highest numerical "score" is taken as the most appropriate solution. Table 12 is taken from Leisch's article and illustrates this numerical approach for the selection of the proper interchange type, in this example alternative two. One of the noteworthy aspects of Leisch's methodology is the costs only constitute twenty-five percent of the evaluation weight.

Oglesby, Bishop and Willeke clearly state the basic problem with most of these before mentioned evaluation techniques.

> "A general criticism of these approaches is that they have failed to recognize the two basic principles of decision making; (a) decisions must be based on the differences among alternatives; and (b) money consequences must be separated from the consequences that are not reducible to money terms, and then the "irreducibles" must be weighed against the money consequences as a part of the decision making process".[2]

Grant and Oglesby make the following statement in reference to highways and freeways, but it also seems very pertinent to the design of an interchange.

TABLE 12 COMPARISON OF ALTERNATIVE INTERCHANGE SOLUTIONS

Source: 1, p. 21

Output Variables (Comparison Items)	Scale Value	1		2		3	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			2x3		2x5		2x7
Operation [30]							
Speeds of operation	(5)	10	50	8	40	6	30
Travel distance	(5)	10	50	9	45	7	35
Safety - compr. & antic.	(5)	10	50	10	50	7	35
Safety aspects - other	(5)	8	40	10	50	7	35
Capacity	(10)	10	100	8	80	6	60
Costs [25]							
Capital	(15)	6	90	9	135	10	150
Operating	(10)	10	100	10	100	10	100
Implementation [15]							
Construction staging	(10)	6	60	10	100	8	80
Maintenance of traf.	(5)	8	40	10	50	10	50
Environmental [30]							
Traffic disturbances	(5)	6	30	10	50	10	50
Aesthetic qualities	(5)	6	30	9	45	8	40
Barrier Effect	(5)	5	25	10	50	7	35
Impact on develop.	(15)	5	75	9	135	10	150
Total (Index Value)	(100)		740		930*		850
(*Best Alternative)							

> "In many cases some consequences of decisions among highway alternatives (interchanges) cannot be expressed in terms of money. Furthermore, the "irreducibles" to whomever they may accrue are relevant to the decision. In these situations the "dollar" answers from the economy study do not dictate the final choice; but on the other hand they provide a money figure against which the irreducibles can be weighed and thereby narrow the area of uncertainty with which the decision maker is faced."[3]

Wattleworth and Ingram tried to overcome these problems by applying the cost effectiveness methodology to the analysis of alternative interchange design configurations. These authors recognized the "need for a procedure that can be quickly used by a designer to compose alternative interchange design (or redesign) configurations and that considers the cost of each configuration as well as the effectiveness of the interchange."[4] The effectiveness measure that was used in this research was the total interchange capacity, expressed in terms of equivalent ADT entering the interchange. The cost measure was in terms of the initial costs of the project. Prior to the development of this cost effectiveness approach, the authors formulated a linear programming model to determine interchange capacity.[5] This linear programming model, itself, would be a good tool to determine the proper interchange configuration, if capacity was the only measure of effectiveness that was used.

During the field interviews, it became apparent that there is no generally accepted evaluation methodology for the comparison of alternative interchange configurations.

In most rural areas there is no problem; diamond interchanges are used most of the time without any comparison to other configurations or without any evaluation of traffic operations, the effect on land use, etc. However, when a decision has to be made because of a complicated design situation, there is no accepted methodology that could be used in the selection of an interchange type.

Based on these previous comments, an appropriate evaluation methodology for the comparison of alternative interchange configurations must include nonmarket variables as well as market variables. And the best way to incorporate these nonmarket variables into an evaluation methodology is through the use of the cost-effectiveness technique. A brief explanation of the cost-effectiveness approach is included in Appendix C.

The application of the cost-effectiveness approach presented in this research results in an Effectiveness Profile which is a set of vertical scales; each vertical scale representing a different criterion. For each alternative design, its effectiveness rating for every evaluation criterion is plotted on the proper vertical scale. Straight lines are then drawn connecting the appropriate effectiveness ratings to form an Effectiveness Profile for each alternative configuration. The final Effectiveness Profile is actually a compilation of two or more cost-effectiveness curves into one graph. The Effectiveness

Profile is an expansion of the community factors profile developed by Oglesby, Bishop and Willeke[6] as a method for decisions among freeway location alternatives based on user and community consequences. Figure 7 is an example of an Effectiveness Profile used to evaluate three alternative interchange configurations. A detailed discussion of how this Effectiveness Profile was developed is contained in Appendix D.

The effectiveness ratings are measured objectively if possible - in terms of level of service, acres required, number of families relocated, etc. - or subjectively - poor, fair, good, excellent - based on the designer's experience, and community attitudes. The bottom line of the Effectiveness Profile represents the lowest or worst possible effectiveness rating and the top line the highest or best possible effectiveness rating for each criterion. Each vertical scale is subdivided into equal segments between these two extreme measures of effectiveness. If no predetermined maximum or minimum value can be set for a vertical scale, then the best effectiveness rating for the given alternative designs should be scaled on the top line and the worst effectiveness rating on the bottom line.

Also, some of the evaluation criteria may have a minimum acceptable effectiveness limitation which is more restrictive than the lowest possible effectiveness rating and is represented by a horizontal line across the vertical scales representing those criteria.

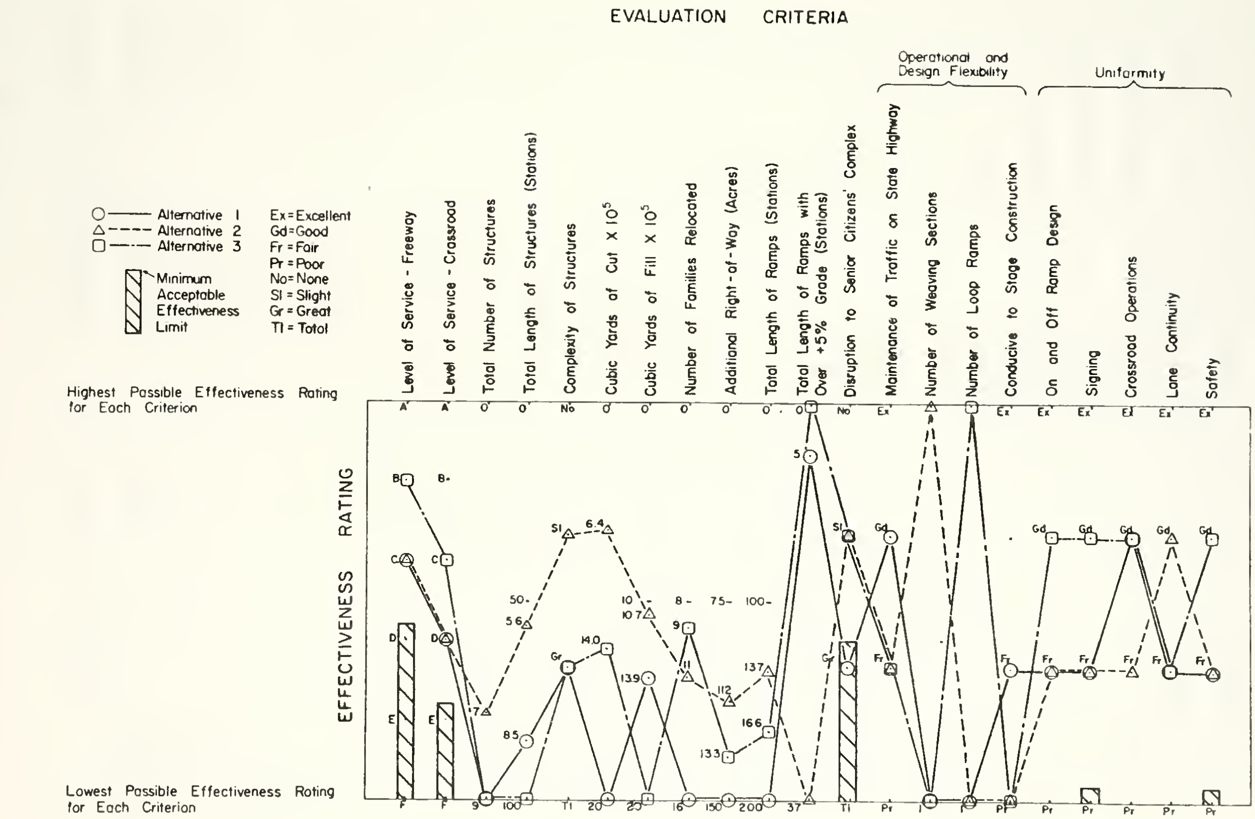


FIGURE 7 EFFECTIVENESS PROFILE

If a minimum acceptable effectiveness limit is assigned to an evaluation criterion, it should be done a priori and not after the Effectiveness Profile has been developed. The segment of the vertical scale below this minimum acceptable effectiveness limit is an area which indicates rejection of any alternative whose effectiveness rating falls in it. This rejection of the alternative design should be final unless conditions are changed which either alter the minimum acceptable effectiveness limit or improve the interchange design so that the alternative's effectiveness rating increases above this limiting constraint. For example, in Figure 7, the criteria, level of service on the freeway and on the crossroad and the disruption to the senior citizens' complex, have minimum acceptable effectiveness limits.

The changing of either the minimum acceptable effectiveness limit or the effectiveness rating because of some design alteration lends itself quite readily to a rough form of sensitivity analysis. By making either of these changes, alterations occur relative to the differences between the alternatives, possibly resulting in the selection of a different alternative design.

Evaluation criteria which indicate similar characteristics for the three alternative interchange designs are not included in the Effectiveness Profile; however, they are important in the decision of whether or not an interchange should be constructed. If all three alternative

configurations have a similar positive characteristic, then any of the three types could be built, based solely on this factor. But, if all three alternative configurations possess the same absolute negative characteristics, then the decision process becomes more complicated. For example, if all three alternatives require the taking of a certain parcel of land which is unattainable, then there is no feasible alternative among the three given; and either additional alternative designs must be developed or the total project abandoned.

Selection of an Interchange Configuration

In the case of a simple design situation where only one interchange configuration is developed, there is no need for an evaluation methodology since the interchange configuration is already selected. However, when a choice must be made between two or more alternative interchange types, the decision maker, be he the interchange design engineer or his superior, should analyze the Effectiveness Profile of each alternative design. After eliminating those alternative designs which do not meet all of the minimum attractive effectiveness limits or are dominated by another alternative design, the decision maker is left with the interchange configurations which meet minimum requirements. In the Effectiveness Profile shown in Figure 7, one of the alternative designs could be quickly eliminated from further consideration. Alternative One causes too much disruption

to the senior citizen's complex, which is unacceptable to the community. The basic decision, then, is between Alternatives Two and Three. After comparing the initial cost of each of these remaining interchange types, the decision maker should be able to make a decision on the type of interchange to design.

This graphical display of alternative consequences, the Effectiveness Profile, should be useful in many ways for the design engineer. It will provide him with an easily understood representation of the overall effects of each alternative design. Besides being an aid to himself and his technical associates, the Effectiveness Profile should be a helpful visual aid at a public meeting, because it clearly illustrates which criteria were used and the effectiveness rating assigned to each alternative for every criteria used. The public may not agree with some of the effectiveness ratings,but at least they will be able to see how the designer arrived at his decision. The public will also be able to visualize the influence of any "absolute" criterion by seeing which alternatives were dropped from further consideration because they did not meet a certain minimum attractive effectiveness limit.

The Effectiveness Profile could be very useful as an indicator of the monetary value of qualifiable variables. After many interchange design evaluations over a long period of time, it may be possible to look back over the

Effectiveness Profiles of past evaluations and formulate a monetary utility for the qualifiable variables or at least recognize which qualifiable criterion carried weight in previous decisions. For example, if a certain evaluation criterion seems to be prevalent when the cheapest design alternative in terms of dollars is not chosen, then it should be possible to assign some dollar value to this criterion.

The Effectiveness Profile should encourage design variations after the initial alternatives have been developed. If an alternative meets all of the evaluation criteria except one or two, the decision maker should feel compelled to see what would happen to the decision outcome if he were to make modifications to the rejected alternative designs so that it would at least meet all of the minimum acceptable effectiveness limits. This procedure will provide the decision maker with a method of evaluating the results of placing certain constraints on the design.

Depending on the selection of evaluation criteria, the Effectiveness Profile should be sensitive enough to register any significant differences in alternative interchange configurations. The operational differences between a tapered off-ramp and a parallel off-ramp will not be noticed unless the designer makes this design element one of the evaluation criteria. Significant design variations - a loop ramp versus a diamond type ramp - will definitely register in the Effectiveness Profile.

The strength of proposed evaluation methodology is contingent on the selection of the evaluation criteria and the development of the Effectiveness Profile. The evaluation methodology is simple to apply and should not require much time. It is felt that these attributes are necessary for the practicing interchange design engineers to use this method in the selection of an interchange configuration.

CHAPTER 7: SUMMARY AND CONCLUSIONS

Summary

Interchanges are the weak links in any freeway system because of the vehicular turbulence associated with the inherent merging, diverging and weaving maneuvers. If the interchanges operate efficiently then traffic on the freeway will probably flow smoothly.

It does not seem probable that many more miles of new freeway will be built, especially in urban areas. However, those that are built will have to pass a stringent test from the ecologists. The same is true for the rehabilitation of existing freeways, which have become corridors lined with intense land development. Many of the existing interchanges need upgrading and yet, with the adjacent land development, there is no easy way to alter these interchange configurations. An interchanges's impact on the community and its traffic operational requirements are opposing forces with which the interchange design engineer must work. He must somehow relate these two forces and arrive at an acceptable interchange configuration. This is the most difficult part in the design of an interchange.

The first step in developing a methodology for the selection of an interchange configuration was to establish a general interchange design philosophy. This philosophy was based on the principle that an interchange is a part of two systems, the freeway system and the local street system and should be designed accordingly. Terms such as flexibility, uniformity, simplicity, anticipatory sight distance, route continuity, lane balance and basic number of lanes were an important part of this interchange design philosophy which finally evolved into eighteen basic interchange design principles and eight secondary interchange design principles.

These design principles formed the basis for two types of evaluation criteria: operational and design factors, and community disruption factors. Included among the operational and design factors were criteria such as level of service continuity on the freeway and on the crossroad, capacity of the interchange, accident potential, route continuity, and signability. It was emphasized that one of the operational factors had to check to see if the anticipated traffic could be carried by each alternative design. The community disruption factors included such factors as the amount of land required outside of the normal right-of-way, the taxable property removed from the tax rolls, the number of families and businesses displaced, the effect on an historical site, and a measure of aesthetics.

Partial lists of both types of factors were developed. These lists were open-ended because it was impossible to determine all of the factors which could influence the selection of an interchange configuration.

After developing a general interchange philosophy and a list of evaluation criteria, an interchange evaluation methodology was formulated. This evaluation methodology consists of four parts.

1. Scrutinize the evaluation criteria to determine which ones are relevant.
2. Estimate the initial cost of each alternative interchange design.
3. Develop an Effectiveness Profile for each alternative design.
4. Compare the initial cost and the Effectiveness Profile for each alternative design and select an interchange configuration.

The selection of pertinent evaluation criteria is fundamental to the evaluation methodology. The criteria chosen should measure differences between the alternative interchange designs. If no such criteria exist, then there is no difference between the alternative designs and the interchange configuration with the lowest initial cost should be selected.

The initial cost was used as the cost indicator for each alternative interchange design. The initial cost was

selected because it is easily obtainable and does not include some of the uncertainties associated with the calculation of road user costs.

The next step in the evaluation methodology is the development of an Effectiveness Profile for each alternative interchange design. An Effectiveness Profile is a graphical technique which shows each alternative's effectiveness rating for every evaluation criterion. It is based on the cost-effectiveness approach of economic analysis and is the accumulation of several cost-effectiveness plots into a single graph. This technique makes it possible to compare and analyze all of the individual Effectiveness Profiles. An Effectiveness Profile should be helpful to both the interchange designer and to the public. It forces the designer to list the evaluation criteria which he used in evaluating the alternative configurations; thereby, allowing the public to better understand how the interchange designer and the decision maker arrived at the selection of a particular interchange type.

The last step in the evaluation methodology is to analyze the initial cost and the Effectiveness Profile for each alternative interchange configuration. This analysis will provide the decision maker with the necessary information to select an adequate interchange configuration for the given conditions.

Conclusions

The following conclusions concerning guidelines for the selection of an interchange configuration summarize the findings of this research:

1. Each interchange design situation has it's own characteristics and should be designed accordingly. A handbook or rote approach to interchange design is unacceptable.
2. A service interchange functions as an interface between two systems, the freeway system and the local street system and, therefore, must be designed with consideration given to both systems. Interchanges should not be designed as isolated elements in either system.
3. An interchange design philosophy, a set of guidelines for good interchange design, was developed from the literature and from contacts with interchange design engineers.
4. Operational, design, and community impact factors as well as costs should be used in the selection of interchange types.
5. An Effectiveness Profile approach was developed to evaluate alternative interchange designs as both quantifiable and qualifiable criteria must be considered.

6. An evaluation methodology, a step by step process which will help the decision maker select an interchange configuration for a particular set of conditions, was developed, is simple to use and is recommended for interchange type selection.

NOTES

NOTES

Chapter 1

1. Virginia, State of, Highway Design Manual - Chapter 5 - Interchanges, p. 5.1.

2. Hong, H. "Some Aspects of Interchange Design." Traffic Engineering, Vol. 36, No. 10, July 1966, p. 27.

3. Leisch, Jack E. "Adaptability of Interchanges to Interstate Highways." ASCE Transactions 1959, Vol. 124, p. 588.

4. Leisch, Jack E., Personal Communications with, Evanston, Illinois, October 27, 1971.

Chapter 2

1. Pinnell, Charles. "Driver Requirements in Freeway Entrance Ramp Design." Traffic Engineering, Vol. 31, No. 3, December 1960, p. 11-17, 54.

2. Pinnell, Charles and C. J. Keese. "Traffic Behavior and Freeway Ramp Design." A.S.C.E., Journal - Highway Division, Vol. 86, No. H.W.3, September 1960, p. 41-58.

3. Loutzenheiser, D. W. "New Concepts for Urban Freeway Interchanges." A.S.C.E., Journal - Highway Division, Vol. 88, No. H.W.1, May 1962, p. 34.

4. Leisch, Jack. Testimony before the Special Subcommittee on the Federal-Aid Highway Program of the Committee on Public Works, House of Representatives, 90th Congress, Second Session, "Freeway Signing and Related Geometrics." (90-39), 1968, p. 361.

5. Hall, Parker. Interchange Design - Personal Notes, California Highway Department, Sacramento, California, 1970, p. 3-6.

6. Fites, Larry A. and M. M. Jacobs. Fundamentals of Geometric Design - 2nd Edition, Institute of Transportation and Traffic Engineering, University of California, Berkeley, California, 1971, p. X-1.

7. Michigan, State Highway Department. A Guide for the Geometric Layout of Interchanges. Lansing, Michigan, 1960, p. 1-2.

8. California, State of. Manual of Instructions - Highway Design, Department of Public Works, Division of Highways, Sacramento, California, 1970, p. 7-504.1.

9. Illinois, State of. Design Manual, Department of Public Works and Buildings, Division of Highways, Bureau of Design, Springfield, Illinois, February 1972, p. 3-305.02.

10. Virginia, State of. Highway Design Manual. Chapter 5 - Interchanges, 1970, p. 5.1.

11. Washington, State of. Highway Design Manual. 3-25 - Interchanges, January, 1972, p. 3-25.01.

12. Nevada, State of. Highway Design Manual. 2-602 - Interchange Types, November 1971, 2-602.1.

13. Tutt, Paul R. "Some Guidelines in the Selection of Freeway Interchanges." Traffic Engineering, Vol. 28, No. 6, March, 1958, p. 11.

14. Hill, George A. "Designing Better Freeways." Traffic Engineering, Vol. 31, No. 1, October 1960, p. 18.

15. Canadian Good Roads Association. Manual of Geometric Design Standards for Canadian Roads and Streets. Geometric Design Committee, Ottawa, Canada, 1963, p. 176.

16. New York, State of. Highway Design Manual - Chapter 6 - Interchanges, New York State Department of Transportation, Albany, New York, p. 6-48, 6-53.6-54.

17. Illinois, State of. Design Manual. p. 3-201.02.

18. Illinois, State of. Design Manual. p. 3-305.02.

19. Virginia, State of. Highway Design Manual. p. 5.7.

20. Best, K. H. "Flyovers and Interchanges." Civil Engineering and Public Works Review, January 1972, p. 41, 43, 45.

21. Gannett, Fleming, Corddry and Carpenter, Inc. "Prospectus - Major Interchange Design, Operation, and Traffic Control." Research Proposal to Federal Highway Administration, p. 13.

22. Leisch, Jack. "Determination of Interchange Types on Freeway Facilities: Systems Engineering Approach." Traffic Engineering, Vol. 43, No. 8, May 1972, p. 21.

23. American Association of State Highway Officials. A Policy on Arterial Highways in Urban Areas. Washington, D.C., 1957, p. 515-516.

24. Colorado, State of. Roadway Design Manual. State Department of Highways, January 1972, p. 5-6.

25. New Mexico, State of. Highway Design Manual, Chapter 7, p. 7-504.1.

26. Canadian Good Roads Association, p. 177.

27. Malone, W. J. Preliminary Design of Free-Flow Highway Interchanges, DeLeuw, Cather and Company of Canada Limited.

28. Canadian Good Roads Association, p. 176, 178.

29. Malone, W. J.

30. Leisch, Jack. Testimony before the Special Subcommittee on the Federal Aid Highway Program of the Committee on Public Works, p. 372.

31. Love, G. D. Discussion of paper by Jack Leisch, "Adaptability of Interchanges to Interstate Highways." ASCE, 1959 Transactions, Vol. 124, p. 614.

32. Barnett, Joseph. "Freeway Operation-Observations Reveal Good and Poor Highway Design." Civil Engineering, Vol. 31, No. 1, January 1961, p. 37.

33. Pinnell, Charles and Johann H. Buhr. "Urban Interchange Design as Related to Traffic Operations - Part 1 - Diamond Interchanges." Traffic Engineering, Vol. 36, No. 6, March 1966, p. 20, 21.

34. Pinnell, Charles and Johann H. Buhr. "Urban Interchange Design as Related to Traffic Operation - Part II - Cloverleaf and Directional Interchanges." Traffic Engineering, Vol. 36, No. 7, April, 1966, p. 51, 53,54.

35. New York, State of. Highway Design Manual, p. 6-51, 6-52.

36. Takebe, Ken-ichi. "Theoretical Analysis of Interchange Composition." A.S.C.E., Transportation Engineering Journal, August 1969, p. 487.

37. Ibid, p. 490.

38. Leisch, Jack. Designing Operational Flexibility into Urban Freeways. 33rd Annual Meeting, I.T.E., Toronto, Canada, August, 1963, p. 2.

39. Leisch, Jack. "Spacing of Interchanges on Freeways in Urban Areas." ASCE, Journal - Highway Division, Vol. 85, No. HW4, Part 1, December 1959, p. 640.

40. Satterly, Gilbert T., Jr. "Spacing of Interchanges and Grade Separations on Urban Freeways." Ph.D. Dissertation, Northwestern University, Evanston, Illinois, 1965, p. 123.

41. Automotive Safety Foundation. Driver Needs in Freeway Signing. for California Department of Public Works, Division of Highways, Washington, D. C., December 1958, p. 21.

42. Webb, George M. Correlation of Geometric Design and Directional Signing. California Division of Highways, January 1959, p. 26.

43. Leisch, Jack. Personal Communication with, Evanston, Illinois, October 27, 1971.

44. Conklin, Robert D. "A Comparison of Vehicle Operating Characteristics Between Parallel Lane and Direct Taper Types of Freeway Off-Ramps." Traffic Engineering, Vol. 30, No. 3, December 1959, p. 16.

45. Fukutome, Ichiro and Karl Moskowitz. "Traffic Behavior and Off-Ramp Design, Freeway Operations." Highway Research Board, NRC, HRB, Highway Research Record 21, Washington, D. C., 1964, p. 31.

46. Gray, Peter and Wayne Kauk. "Circular and Elongated Freeway Exit Loop Ramps." Traffic Engineering, Vol. 38, No. 7, April 1968, p. 19.

47. Pinnell and Keese, p. 58.

48. American Association of State Highway Officials. "Report of the Special Freeway Study and Analysis Committee to the Executive Committee of the American Association of State Highway Officials." 1960, p. 10.

49. Roth, Walter J. "Interchange Ramp Color Delineation and Marking Study." Highway Research Board Record 325, Washington, D. C., 1970, p. 49.

50. Berarducci, Alfred and John J. Dobelek. "Freeway Entrance and Exit Controls." Traffic Quarterly, Vol. 31, No.1, January 1959, p. 24.

51. Tipton, William E. and Charles Pinnell. "An Investigation of Factors Affecting the Design Location of Freeway Ramps." Highway Research Board Record 152, Washington, D. C., 1967, p. 29.

52. Berry, Donald, G. L. D. Ross and R. C. Pfefer. "A Study of Left-Hand Exit Ramps on Freeways." Highway Research Board Record 21, Washington, D. C., 1964, p. 15.

53. Goodman, Leon. "Interchange Design to Eliminate Wrong Way Entry." Traffic Engineering, Vol. 40, No. 1, October, 1969, p. 35.

54. California, State of. Manual of Instructions - Highway Design, p. 7-505.7.

55. Ibid, p. 7-505.7.

56. Highway Research Board. Highway Capacity Manual. Special Report 87, Washington, D. C., 1965, p. 166.

57. Pignataro, Louis, J. and W. R. McShane, K. W. Crowley, B. Lee and R. P. Roess. "Weaving Area Operations Study: Analysis and Recommendations." Highway Research Board Paper, Polytechnic Institute of Brooklyn, January 1972, p. 20.

58. Michigan, State Highway Department of. A Guide for the Geometric Layout of Interchanges. Lansing, Michigan, 1960, p. 42.

59. Norman, O. K. "Operation of Weaving Areas." Highway Research Board Bulletin 167, Washington, D. C., 1959, p. 38.

60. Texas, State of. Design Manual for Controlled Access Highways. Texas Highway Department, Austin, Texas, January 1960, p. 4-54, 4-62.

61. Pinnell, Charles and Paul R. Tutt. "Evaluation of Frontage Roads as an Urban Freeway Design Element." Highway Research Board Record 9, Washington, D. C., 1963, p. 24.

62. American Association of State Highway Officials. "Report by the Special Freeway Study and Analysis Committee to the Executive Committee of the American Association of State Highway Officials." 1960, p. 15.

63. Pinnell, Charles and Donald G. Capelle. "Operational Study of Signalized Diamond Interchanges." Highway Research Board Bulletin 324, Washington, D. C., 1962, p. 38.

64. California, State of. Manual of Instructions - Highway Design, p. 7-505.4.

65. Leisch, Jack. Designing Operational Flexibility into Urban Freeways, p. 4.

66. California, State of. Manual of Instructions - Highway Design, p. 7-505.10.

67. Leisch, Jack. Testimony before the Special Subcommittee on the Federal-Aid Highway Program of the Committee on Public Works, House of Representatives, p. 384.

68. Federal Highway Administration. "Policy and Procedure Memorandum 90-1, Guidelines for Implementing Section 102(2)(c) of the National Environmental Policy Act of 1969, Section 1653(f) of 49 U.S.C., Section 479f 16 U.S.C., and Section 309 of the Clean Air Act of 1970." U. S. Department of Transportation, Washington, D. C., August 1971, p. 1, 3.

69. Ibid, p. 1.

70. O'Leary, J. D., Jr. "Evaluating the Environmental Impact of an Urban Expressway." Traffic Quarterly, Vol. XXIII, No. 3, July 1969, p. 350.

71. Garrison, William L. "Supply and Demand for Land at Highway Interchanges." Highway Research Board Bulletin 288, Washington, D. C., 1961, p. 66.

72. Greenbie, Barrie B. "Interchange Planning in a Rural Area." Traffic Quarterly, Vol. 24, No. 2, April, 1970, p. 266.

73. Thiel, F. I. "Highway Interchange Area Development." Public Roads, Vol. 33, No. 8, June 1965, p.153.

74. Kuhn, Herman A. "Planning Implications of Urban and Rural Freeway Interchanges." A.S.C.E. Journal of Urban Planning and Development Division, Vol. 95, No. UPI, April 1969, p. 90.

75. Stein, Martin M. "Highway Interchange Area Development - Some Recent Findings." Public Roads, Vol. 35, No. 11, December 1969, p. 249.

76. Illinois, State of. Your Community at the Crossroads - The Need for Interchange Area Planning. Illinois Division of Highways, Springfield, Illinois, 1970, p. 12.

77. Levin, David R. "The Highway Interchange Land Use Problem." Highway Research Board Bulletin 288, Washington, D. C., 1961, p. 4.

78. California, State of. Manual of Instructions - Highway Design. p. 7-504.1.

79. Leisch, Jack. "Determination of Interchange Types on Freeway Facilities: Systems Engineering Approach." p. 16.

Chapter 3

No Notes.

Chapter 4

1. New York, State of. Highway Design Manual - Chapter 6 - Interchanges. New York State Department of Transportation, Albany, New York, p. 6-48.

2. Fites,Larry A. and M. M. Jacobs. Fundamentals of Geometric Design - 2nd Edition, Institute of Transportation and Traffic Engineering, University of California, Berkeley, California, 1971, p. X-11.

3. Leisch, Jack. Designing Operational Flexibility into Urban Freeways. 33rd Annual Meeting, I.T.E., Toronto, Canada, August 1963, p. 27.

4. Canadian Good Roads Association. Manual of Geometric Design Standards for Canadian Roads and Streets, Geometric Design Committee, Ottawa, Canada, 1963, p. 176.

5. Northwestern University. Geometric Design of Freeways and Interchanges. The Traffic Institute, Evanston, Illinois, Feb. 1968, p. 9.

6. Ibid, p. 12.

7. Hall, Parker. Interchange Design - Personal Notes, California Highway Department, Sacramento, California, 1970, p. 4.

8. Leisch, Jack. Personal Communications with, Evanston, Illinois, October 27, 1971.

Chapter 5

1. Cirillo, J. A., S. K. Dietz and R. L. Beatty. Analysis and Modeling of Relationships Between Accidents and the Geometric and Traffic Characteristics of the Interstate System. U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., August 1969, p. 11.

2. Canadian, Good Roads Association. Manual of Geometric Design Standards for Canadian Roads and Streets, Geometric Design Committee, Ottawa, Canada, 1963, p. 168.

3. American Association of State Highway Officials. A Policy on Arterial Highways in Urban Areas. Draft copy of 2nd Edition, Chapter J - Interchanges, Washington, D. C., May 1972, p. 7.

4. Ibid, p. 6.

Chapter 6

1. Leisch, Jack. "Determination of Interchange Types on Freeway Facilities: Systems Engineering Approach." Traffic Engineering, Vol. 42, No. 8, May 1972, p. 21.

2. Oglesby, C. H., Bruce Bishop and G. E. Willeke. "A Method for Decisions Among Freeway Location Alternatives Based on User and Community Consequences." Highway Research Board Record 305, Socioeconomic Considerations in Transportation Planning, Washington, D. C., 1970, p. 1.

3. Grant, E. L. and C. H. Oglesby. "Economy Studies for Highways." Highway Research Board Bulletin 306, Washington, D. C., 1961, p. 24.

4. Wattleworth, J. A. and J. W. Ingram. "Cost-Effectiveness Technique for Analysis of Alternative Interchange Design Configurations." Highway Research Board Record 390, Geometric Design Implications and Vehicle Noise, Washington, D. C., 1972, p. 27.

5. Wattleworth, J. A. and J. W. Ingram. "A Capacity Analysis Technique for Highway Junctions." (Abridgment), Highway Research Board Record 398, Washington, D. C., 1972, p. 36.

6. Oglesby, C. H., Bruce Bishop and G. E. Willeke, p. 8.

Chapter 7

No Notes.

BIBLIOGRAPHY

BIBLIOGRAPHY

Alberta, Province of. Urban Highway Design Guide. Department of Highways and Transport. Edmonton, Alberta, Canada.

Alexander, C. and M. L. Manheim. "The Design of Highway Interchanges: An Example of a General Method for Analyzing Engineering Design Problems". Highway Research Board Record No. 83, Geometric Design and Barrier Rails, Washington, D. C., 1965.

American Association of State Highway Officials. A Policy on Arterial Highways in Urban Areas. Washington, D. C., 1957.

American Association of State Highway Officials. A Policy on Arterial Highways in Urban Areas. Draft copy, Washington, D. C., 1972.

American Association of State Highway Officials. A Policy on Geometric Design of Rural Highways. Washington, D. C., 1965.

American Association of State Highway Officials. Highway Design and Operational Practices Related to Highway Safety. Washington, D. C., February 1967.

American Association of State Highway Officials. Manual for Signing and Pavement Marking of the National System of Interstate and Defense Highways. Washington, D. C., 1970.

American Association of State Highway Officials. "Report by the Special Freeway Study and Analysis Committee to the Executive Committee of the American Association of State Highway Officials", 1960.

Automotive Safety Foundation. Driver Needs in Freeway Signing, for California Department of Public Works Division of Highways, Washington, D.C., December 1958.

Barnett, James D. and Charles Pinnell. At-Grade Intersection Spacing on Conventional Two-Level Diamond Interchanges. Research Project HPS 1-(27)-G, Texas A & M.

Barnett, Joseph. "Freeway Operation - Observations Reveal Good and Poor Highway Design." Civil Engineering, Vol. 31, No. 1, January 1961, p. 35-38

Barton-Aschman Associates. Highway and Land-Use Relationships in Interchange Areas. A study conducted for the Illinois Division of Highways, January 1968.

Berarducci, Alfred and John J. Dobelek. "Freeway Entrance and Exit Controls," Traffic Quarterly, Vol. 13, No. 1, January 1959, p. 20-33.

Berry, Donald, G. L. D. Ross and R. C. Pfefer. "A Study of Left-Hand Exit Ramps on Freeways." Highway Research Board. Freeway Operations. Record No. 21. Washington, D. C.: 1964, p. 1-16.

Best, K. H. "Flyovers and Interchanges." Civil Engineering and Public Works Review, January 1972, pp. 41, 43, 45.

Bidell, William. "Trend in and Re-Appraisal of Interchange Forms Based on Operational Experience." ITE Proceedings, 1964, pp. 96-106.

Breuning, S. M. "Highway Turbine Interchanges." Traffic Engineering, Vol. 28, No. 7, April 1958, pp. 19-21, 30-31.

Buhr, Johann H. "A Comparison of Construction Costs of Internal and External Diamond Interchanges on a Depressed Freeway." Seminar Paper, Northwestern University, May 1964.

Butcher, F. C. "Urban Freeway Interchanges - Economics and Planning." Proceedings of the 14th California Street and Highway Conference. Institute of Transportation and Traffic Engineering, University of California, 1962, pp. 103-105.

California, State of. Manual of Instructions - Design. Department of Public Works, Division of Highways, Sacramento, California, 1970.

Canadian Good Roads Association. Manual of Geometric Design Standards for Canadian Roads and Streets. Geometric Design Committee, Ottawa, Canada, 1963.

Capelle, D. G. and C. Pinnell. "Capacity Study of Signalized Diamond Interchanges." Highway Research Board Bulletin 291, pp. 1-25, 1961.

Cirillo, J. A. "The Relationship of Accidents to Length of Speed Change Lanes and Weaving Areas on Interstate Highways." Highway Research Board Record No. 312, pp. 17-32, 1970.

Cirillo, J. A., S. K. Dietz and R. L. Beatty. "Analysis and Modeling of Relationships Between Accidents and the Geometric and Traffic Characteristics of the Interstate System." U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., August 1969.

Colorado, State of. Roadway Design Manual. State Department of Highways, January 1972.

Conklin, Robert D. "A Comparison of Vehicle Operating Characteristics Between Parallel Lane and Direct Taper Types of Freeway Off-Ramps." Traffic Engineering, Vol. 30, No. 3, December 1959, pp. 13-17.

Cornelius, M. E. "Geometric Design of Roads and Streets: The Effect of Interchange Design on Land Use." Proceedings of the Sixteenth California Street and Highway Conference (Abstracts), Institute of Transportation and Traffic Engineering, University of California, 1964, pp. 50-51.

Covault, Donald O. and R. C. Kirk. "Influence of Off-Ramp Spacing on Traffic Flow Characteristics on Atlanta Freeway and Arterial Street System." Highway Research Board Record No. 59, Freeway Operations. Washington, D. C., pp. 39-52.

Covault, Donald O. and Robert P. Roberts. "Influence of On-Ramps Spacing on Traffic Flow on Atlanta Freeway and Arterial Street System." Highway Research Board, Freeway Operations. Record No. 21. Washington, D. C., 1964, p. 32-47.

Drew, D. R. and C. J. Keese. "Freeway Level of Servcie as Influenced by Volume and Capacity Characteristics." Texas Transportation Institute, College Station, Texas, 1965.

Dudek, C. L. and W. R. McCasland. "Cost-Effectiveness of Freeway Merging Operations." Highway Research Board, Operational Improvements for Freeways, Record 363, Washington, D. C., 1971, pp. 43-59.

Echterhoff-Hammerschmid, Helmut. "A Study of Gap Acceptance at Left-Hand and Right-Hand Ramps." M.S. Thesis, Northwestern University, Evanston, Illinois, 1965.

Edwards, H. M. and J. L. Vardon. "Some Factors Affecting Merging Traffic on the Outer Ramps of Highway Interchanges." Report 42, Queen's University, Kingston, Ontario, January 1968.

English, J. Morley. Cost-Effectiveness - The Economic Evaluation of Engineering Systems. John Wiley and Sons, Inc., New York, 1968.

Federal Highway Administration. A Handbook of Highway Safety Design and Operating Practices. U. S. Dept. of Transportation, Washington, D. C., 1968, 38 p. + supplement #2, Nov. 1969.

Federal Highway Administration. Manual on Uniform Traffic Control Devices. U. S. Dept. of Transportation. Washington, D. C., 1971.

Federal Highway Administration. "Policy and Procedure Memorandum 90-1, Guidelines for Implementing Section 102(2)(c) of the National Environmental Policy Act of 1969, Section 1653(f) of 49 U.S.C., Section 470 of 16 U.S.C., and Section 309 of the Clean Air Act of 1970." U. S. Department of Transportation, Washington, D. C. , August 1971.

Fisher, R. L. "Accident and Operating Experience at Interchanges." Highway Research Bulletin No. 291, pp. 124-138, 1961.

Fites, Larry A. and M. J. Jacobs. Fundamentals of Geometric Design - 2nd Edition. Institute of Transportation and Traffic Engineering, University of California, Berkeley, California, 1971.

Franklin Engineering Associates, Limited. Development and Demonstration of Improved Engineering Productivity for the Design Phase of Pre-Construction Engineering. Chapter III Interchange Design, Bureau of Public Roads, May 1967.

Friebele, J. D., C. J. Messer and C. L. Dudek. "State-of-the Art of Wrong-Way Driving on Freeways and Expressways." Research Report 139-7, Study 2-8-69-139, Texas Transportation Institute, Texas A & M University, June 1971.

Fukutome, Ichiro and Karl Moskowitz. "Traffic Behavior and Off-Ramp Design." Highway Research Board, Freeway Operations, Record No. 21, Washington, D. C., 1964, p. 17-31.

Fukutome, Ichiro and Karl Moskowitz. "Traffic Behavior and On-Ramp Design." Highway Research Board, Traffic Behavior on Freeways, Bulletin No. 235, Washington, D. C., 1960, pp. 38-72.

Gannett, Fleming, Corddry and Carpenter, Inc. "Prospectus - Major Interchange Design, Operation, and Traffic Control." Research Proposal for Federal Highway Administration, 1971.

Garrison, William L. "Supply and Demand for Land at Highway Interchanges." Highway Research Board, Land Use and Development at Highway Inte-changes, Bulletin 288, Washington, D. C., 1961, pp. 61-66.

Garver and Garver, Inc. Preliminary Design Memorandum - Interchange Route I-93 with US 63 near Turrell, Arkansas. Little Rock, Arkansas, 1957.

Gern, Richard and Harvey R. Joyner. "Cross Route Access Design in Interchange Areas," Paper presented at the Highway Research Board 43rd Annual Meeting, Washington, D. C., January 1964.

Glass, M. "Ramp Terminal Channelization." ITE Proceedings, pp. 186-203, 1959.

Goldman, Thomas A. Cost-Effectiveness Analysis - New Approaches in Decision-Making. Washington Operations Research Council, Frederick A. Praeger, Inc., New York 1966.

Goodman, Leon. "Interchange Design to Eliminate Wrong Way Entry." Traffic Engineering, Vol. 40, No. 1, October 1969, pp. 28-31, 34-35.

Grant, E. L. and C. H. Oglesby. "Economy Studies for Highway." Highway Research Board Bulletin 306, Washington, D. C., 1961, pp. 23-38.

Gray, Peter and Wayne Kauk. "Circular and Elongated Freeway Exit Loop Ramps." Traffic Engineering, Vol. 38, No.7, April 1968, pp. 16-19.

Greenbie, Barrie B. "Interchange Planning in a Rural Area." Traffic Quarterly, Vol. 24, No. 2, April 1970, pp. 265-278.

Grimes, G. N. "Lane Drop Study at the Davidson Expressway on I-75 (Chrysler Freeway)" Report TSD-G-198-72, Michigan Department of State Highways, Lansing, Michigan, March 1972.

Guerin, Neil S. "Design Standards for Freeways in Australia." Traffic Engineering, Vol. 42, No. 2, Nov. 1971, pp. 25-27.

Hall, Parker. Interchange Design - Personal Notes. Calif. Highway Department, Sacramento, California, 1970.

Hartigan, M. J. "The Correlation of Design and Adquate Signing on Freeways." AASHO, Proceedings, pp. 184-188, 1957.

Hartigan, Michael J. "Potential of Reversible Lanes and Continuous Collector-Distributor Roads on Freeways." 1964 Proceedings, Institute of Traffic Engineerings, November 1964, pp. 107-118.

Heanue, K. E. and D. O. Covault. "The Development of Criteria for Closing a Freeway Ramp Using Linear Programming." Paper, 1962.

Heroy, Frank M., Jr. "Directional Diamond Interchanges." Traffic Engineering, Vol. 32, No. 4, January 1962, p. 47.

Hess, J. W. "Capacities and Characteristics of Ramp-Freeway Connections." Highway Research Board Record No. 27, pp. 69-115, 1963.

Hess, J. W. "Ramp-Freeway Terminal Operation as Related to Freeway Lane Volume Distribution and Adjacent Ramp Influen-e." Highway Research Board Record No. 99, pp. 81-116, 1965.

Highway Research Board. "Freeway Operations." HRB Bibliography 28, Washington, D. C., 1961.

Highway Research Board. Highway Capacity Manual. Special Report 87, Washington, D. C., 1965.

Highway Research Board. "Protection of Highway Utility." N.C.H.R.P. Report 121, Washington, D. C., 1971.

Hill, George A. "Designing Better Freeways." Traffic Engineering, Vol. 31, No. 1, Oct. 1960, pp. 11-18.

Hong, H. "Some Aspects of Interchange Design." Traffic Engineering, Vol. 36, No. 10, July 1966, pp. 26-30.

Horwood, E. M., C. H. Graves and C. D. Rodgers. "An Evaluation of Land Use Controls Procedures at Freeway Approaches." Highway Research Board, Land Use and Development at Highway Interchanges, Bulletin 288, Washington, D. C., 1961, pp. 67-82.

Hulbert, Slade. "Signing a Freeway to Freeway Interchange." The Institute of Transportation and Traffic Engineering, University of California, Research Report 42, Sept. 1965.

Hulbert, Slade. "Wrong-Way Driving Off-Ramp Studies." Instituee of Transportation and Traffic Engineering Research Report #39, University of California.

Huvane, Barbara, A. "Construction Cost of Expressways." Transportation Engineering Journal, ASCE, Vol. 97, No. TE2, Proc. Paper 8113, May 1971, pp. 173-186.

Illinois, State of. Design Manual. Department of Public Works and Buildings, Division of Highways, Bureau of Design, Springfield, Illinois, Feb. 1972.

Illinois, State of. Your Community at the Crossroads - The Need for Interchange Area Planning. Illinois Division of Highways, Springfield, Illinois, 1970.

Institute of Traffic Engineers. "Freeway Operations. New Information on Emerging Responsibilities."

Institute of Traffic Engineers. Notes - Seminar on Dynamic Design for Safety, May 1972.

Institute of Traffic Engineers. "System Considerations for Urban Freeways." Washington, D. C., Oct. 1967.

Institute of Transportation and Traffic Engineering. "Highway Capacity-Computer Programs and Simulation Studies." Reprint No. 158 from Traffic Engineering, University of California, 1969.

Institute of Transportation and Traffic Engineering. "Selected References on Traffic Engineering." University of California, No. 29, July 1965.

Jones, John Hugh, The Geometric Design of Modern Highways. London, 1961.

Keese, C. J., C. Pinnell and W. R. McCasland. "A Study of Freeway Traffic Operation." Highway Research Board Bulletin 235, pp. 73-132, 1959.

Keese, C. J. and R. H. Schleider. "The Correlation of Design and Operational Characteristics of Expressways in Texas." Highway Research Board Bulletin 170, pp. 1-23, 1957.

Kenyon, R. H. "The Location of Interchanges in Urban Areas." AASHO <u>Proceedings</u>, pp. 198-204, 1958.

Kuhn, Herman. "Planning Implications of Urban and Rural Freeway Interchanges." ASCE, <u>Journal of the Urban Planning and Development Division</u>, Vol. 95, No. UP1, April 1969, pp. 81-92.

Langsner, George. "Design Features that Have Enhanced the Performance of the Hollywood Freeway." California Division of Highways, Dec. 1959.

Leisch, Jack E. "Adaptability of Interchanges to Interstate Highways." A.S.C.E. <u>Transactions 1959</u>, Vol. 124, pp. 588-616.

Leisch, Jack E. "Arterial Highways in Urban Areas." Belfast, Ireland, February 1965.

Leisch, Jack E. "Capacity Analysis Techniques for Design of Signalized Intersections - High Type Facilities and Interchanges." <u>Public Roads</u>, Vol. 34, No. 10, Oct. 1967, pp. 211-226.

Leisch, Jack E. <u>Designing Operational Flexibility into Urban Freeways</u>. 33rd Annual Meeting, I.T.E., Toronto, Canada, Aug. 1963.

Leisch, Jack E. "Determination of Interchange Types on Freeway Facilities: Systems Engineering Approach." <u>Traffic Engineering</u>, Vol. 42, No. 8, May 1972, pp. 16-24.

Leisch, Jack E. <u>Interchange Design</u>. Chicago, DeLeuw, Cather and Co., 1962.

Leisch, Jack E. <u>Lane Distribution Techniques for Freeway Facilities</u>. Reprinted from Canadian Good Roads Association Proceedings, 1965.

Leisch, Jack. Personal Communications with Mr. Leisch. Evanston, Illinois, October 27, 1971.

Leisch, J. E. "Spacing of Interchanges on Freeways in Urban Areas." <u>Journal, Highway Division</u>, A.S.C.E., Vol. 85, N. HW4, Pt 1, Dec. 1959, pp. 61-75.

Leisch, Jack E. Testimony before the Special Subcommittee on the Federal Aid Highway Program of the Committee on Public Works, House of Representatives, 90th Congress, Second Session. "Freeway Signing and Related Geometrics" (90-39), 1968, pp. 349-399.

LeRoy, H. M. and J. W. Clinton. "Signalization of Diamond Interchanges." ITE Proceedings, pp. 196-202, 1960.

Levin, David R. "The Highway Interchange Land Use Problem." Highway Research Board Bulletin 288, Washington, D. C., 1961, p. 1-24.

Loutzenheiser, D. W. "New Concepts for Urban Freeway Interchanges." American Society of Civil Engineers, Journal of the Highway Division, Vol. 88, No. HW1, May 1962, pp. 29-41.

Loutzenheiser, D. W. and E. P. Holahan. "Ramp Design - A Survey of State Practices." 1970 Proceedings. American Association of State Highway Officials, Washington, D. C., 1970, pp. 91-98.

Loutzenheiser, D. W. and Jack E. Leisch. Preliminary Design of a Major Interchange. Public Roads Administration, Federal Works Agency, April 1948.

Love, G. D. Discussion of paper by Jack Leisch, Adaptability of Interchanges to Interstate Highways, ASCE, 1959 Transactions, Vol. 124, pp. 588-616.

Lundy, Richard A. "The Effects of Ramp Type Geometry on Accidents." California Highway Department, May 1965, also Highway Research Board Record 163, 1967.

Lyden, F. J. and E. G. Miller. Planning Programming Budgeting: A Systems Approach to Management. Graduate School of Public Affairs, University of Washington, Markham Publishing Co., Chicago, April 1968.

Malone, W. J. Preliminary Design of Free-Flow Highway Interchanges, DeLeuw, Cather and Company of Canada Limited.

Marble, Duane F. "User Service and the Demand for Land at Interchange Points." Highway Research Board Bulletin 288, Washington, D. C., 1961, pp. 25-31.

McDermott, Joseph M. and Charles H. McLean. "Improving Traffic Flow at Transfer Roadways on Collector-Distributor Type Expressways." Paper, 1964.

McEachern, Cooper. "The Three-Level Diamond Interchange." 1961 Proceedings, Institute of Traffic Engineers, Washington, D. C., 1961, pp. 96-105.

Michigan, State Highway Department. A Guide for the Geometric Layout of Interchanges. Lansing, Michigan, 1960, 46p.

Morawski, T. J. "Interchange Spacing and Lane Distribution." Traffic Engineering, Vol. 28, No. 8, May 1958, p. 21-23.

Moskowitz, K. and L. Newman. "Traffic Bulletin No. 4 - Note on Freeway Capacity." Highway Research Board Record 27, pp. 44-68, 1963.

Nash, A. M., D. H. B. Starr and A. H. Bell. "Types of Interchanges." AASHO, Proceedings, 1946, pp. 186-199.

Nevada, State of. Highway Design Manual. Interchange Types (2-602), Nov. 1971.

Neve, James P., Jr. "A Scorecard for Interchanges." Traffic Engineering, Vol. 32, No. 12, Sept. 1962, pp. 22-23 and 35.

Newman, L., A. Dunnet and G. J. Meis. "Freeway Ramp Control - What It Can and Cannot Do." Traffic Engineering, Vol. 19, No. 7, June 1969, pp. 14-21.

New Mexico, State of. Highway Design Manual - Chapter 7.

New York, State of. Highway Design Manual - Chapter 6 - Interchanges. New York State Dept. of Transportation, Albany, New York.

Norman, O. K. "Operation of Weaving Areas." Highway Research Board Bulletin 167, Washington, D. C., 1959, pp. 38-41.

Northwestern University. Geometric Design of Freeways and Interchanges. The Traffic Institute, Evanston, Illinois, Feb. 1968.

Northwestern University. "Left Hand Ramps for Freeways - An Annotated Bibliography." Evanston, Illinois, 1962.

Northwestern University. "Warrants for Highway-Highway Grade Separations Project - An Annotated Bibliography." Evanston, Illinois, 1964.

Northwestern University. "Warrants for Highway-Highway Grade Separations Projects - An Annotated Bibliography." Evanston, Illinois, 1965.

Ockert, C. W. and C. R. Walker. "Criteria to be Used in Developing Warrants for Interchanges on Rural Expressways." Highway Research Board Record 244, Washington, D. C., 1968, pp. 69-86.

Oglesby, C. H., Bruce Bishop and G. E. Willeke. "A Method for Decisions Among Freeway Location Alternatives Based on User and Community Consequences." Highway Research Board Record 305, Washington, D. C., 1970, p. 1-15.

Oglesby, C. H. and L. I. Hewes, Highway Engineering. John Wiley and Sons, Inc., New York, New York, 1963.

O'Leary, J. D., Jr. "Evaluating the Environmental Impact of an Urban Expressway." Traffic Quarterly, Vol. XXIII, No. 3, July 1969, pp. 341-351.

Oppenlander, J. C. and R. F. Dawson. "Interchanges - Chapter 9" - Traffic Control and Roadway Elements - Their Relation to Highway Safety/Revised, Highway Users Federation for Safety and Mobility, Washington, D. C., 1970.

Owens, Terry J. "Some Aspects of Freeway Design and Operation." Traffic Engineering, Vol. 27, No. 7, April 1957, pp. 318-319, 333.

Peterson, J. M. "Freeway Spacing in an Urban Freeway System." Journal, Highway Division, ASCE, Vol. 86, No. HW3, Sept. 1966, pp. 29-39.

Pfefer, Ronald C. "Two Lane Entrance Ramps." Traffic Engineering, Vol. 39, No. 2, Nov. 1968, pp. 18-23.

Pignataro, Louis J., W. R. McShane, K. W. Crowley, B. Lee and R. P. Roess. "Weaving Area Operations Study; Analysis and Recommendations." Highway Research Board Paper, Polytechnic Institute of Brooklyn, January 1972.

Pinnell, C. "Driver Requirements in Freeway Entrance Ramp Design." Traffic Engineering, Vol. 31, No. 3, pp. 11-17, 54, Dec. 1960.

Pinnell, Charles. Guide to the Selection of Nondirectional Interchanges. Texas Transportation Institute Project 2-8-58-6, 1963.

Pinnell, Charles and Charles J. Keese. "Traffic Behavior and Freeway Ramp Design." Journal, Highway Division, ASCE, Vol. 86, No. HW3, Sept. 1960, pp. 41-58.

Pinnell, Charles and Donald G. Capelle. "Operational Study of Signalized Diamond Interchanges." Highway Research Board Bulletin 324, Washington, D. C., 1962, pp. 38-72.

Pinnell, Charles and Johann H. Buhr. "Urban Interchange Design as Related to Traffic Operations - Part 1 - Diamond Interchanges." Traffic Engineering, Vol. 36, No. 6, March, 1966, pp. 20-30.

Pinnell, Charles and Johann H. Buhr. "Urban Interchange Design as Related to Traffic Operation - Part II - Cloverleaf and Directional Interchanges." Traffic Engineering, Vol. 36, No. 7, April, 1966, pp. 51-57.

Pinnell, Charles and Paul R. Tutt. "Evaluation of Frontage Roads as an Urban Freeway Design Element." Highway Research Board Record 9, Washington, D. C., 1963, pp. 1-24.

Rich, M. M. "Correlation of Geometric Design and Directional Signing." AASHO, Proceedings 1956, pp. 131-135.

Roth, Walter J. "Interchange Ramp Color Delineation and Marking Study." Highway Research Board Record 325, Washington, D. C., 1970, pp. 36-50.

Sadai, Yoshiaki. "Accident Analysis of Freeway Interchanges." Traffic Engineering, Vol. 31, No. 6, pp. 20-22, March 1961.

Satterly, G. T., Jr. "Spacing of Interchanges and Grade Separations on Urban Freeways." Ph.D. Dissertation, Northwestern University, Evanston, Illinois, 1965.

Satterly, G. T., Jr. and D. S. Berry. "Spacing of Interchanges and Grade Separations on Urban Freeways." Highway Research Board Record 172, Washington, D. C., 1967, pp. 54-93.

Schoppert, D. W., K. Moskowitz, S. Hulbert and A. Burg. "Some Principles of Freeway Directional Signing Based on Motorist Experience." Highway Research Board Bulletin No. 244, pp. 30-87, 1960.

Seiler, Karl III. Introduction to Systems Cost-Effectiveness. Wiley-Interscience, New York, 1969.

Smith, J. G. "Junction Design on Motorways." Roads and Road Construction, Vol. 38, No. 448, April 1960, pp. 106-111.

Stanhagen, William H. "Highway Interchanges and Land Use Controls." Highway Research Board Bulletin 288, Washington, D. C., 1961, pp. 32-60.

Stark, Harry E. "Freeway Design Elements." Traffic Engineering, Vol. 31, No. 5, Feb. 1961, pp. 17-21.

Stein, Martin M. "Highway Interchange Area Development - Some Recent Findings." Public Roads, Vol. 35, No. 11, Dec. 1969, pp. 241-250.

Takebe, Ken-ichi. "Effect of Ramp Alignment on Operational Characteristics." Traffic Engineering and Control, Sept. 1968, pp. 240-244.

Takebe, Ken-ichi. "Theoretical Analysis of Interchange Composition." Transportation Engineering Journal, ASCE, Aug. 1969, pp. 483-504.

Texas, State of. Design Manual for Controlled Access Highways, Texas Highway Department, Austin, Texas, Jan. 1960.

Thiel, F. I. "Highway Interchange Area Development." Public Roads, Vol. 33, No. 8, June 1965, pp. 153-166.

Thomas, J. M. "Simple Ramp Metering Device Reduces Rear-end Collision." Traffic Engineering, June 1969, pp. 22-25.

Tipton, William E. and Charles Pinnell. "An Investigation of Factors Affecting the Design Location of Freeway Ramps." Highway Research Board Record 152, Washington, D. C., 1967, pp. 1-35.

Tutt, Paul R. "Some Guidelines in the Selection of Freeway Interchanges." Traffic Engineering, Vol.. 28, No. 6, March 1958, pp. 11-14, 24.

Virginia, State of. Highway Design Manual - Chapter 5 - Interchanges.

Walker, Charles R., Jr. "Extension of Criteria to be Used in Developing Warrants for an Interchange at a Major Rural Isolated Interchange." Northwestern University, Evanston, Illinois, Sept. 1966.

Warren, W. L. "Urban Freeways Interchanges - Studies of Ramp Operations." Proceedings of the 14th California Street and Highway Conference, Institute of Transportation and Traffic Engineering, University of California, 1962, pp. 97-102.

Washington, State of. Highway Design Manual. Jan. 1972.

Wattleworth, Joseph A. and Jerry W. Ingram. "A Capacity Analysis Technique for Highway Junctions." (Abridgment), Highway Research Board Record 398, Washington, D. C., 1972, pp. 31-36.

Wattleworth, Joseph A. and Jerry W. Ingram. "Cost-Effectiveness Technique or Analysis of Alternative Interchange Design Configurations." Highway Research Board Record 390, Washington, D. C., 1972, pp. 27-35.

Wattleworth, Joseph A., Johann H. Buhr, D. R. Drew and Frank A. Gerig, Jr. "Operational Effects of Some Entrance Ramp Geometrics on Freeway Merging." Highway Research Board Record 208, Washington, D. C., 1967, pp. 79-113.

Webb, George M. Correlation of Geometric Design and Directional Signing. California Division of Highways, January 1959.

Wegmann, F. J. "State of the Art - Warrants for Highway-Highway Grade Separations." Illinois Division of Highways, Dec. 1964.

Wegmann, F. J., C. A. Walker, and G. T. Satterly, Jr. Existing Practice-Location of Interchanges and Grade Separations in the State of Illinois, Project IHR-55, Illinois Division of Highways, Oct. 1965.

Winch, David M. The Economics of Highway Planning, University of Toronto Press, 1963.

Winfrey, Robley. Economic Analysis for Highways. International Textbook Company, Scranton, Pa., 1969.

Winfrey, R. and C. Zellner. "Summary and Evaluation of Economic Consequences of Highway Improvements." NCHRP Report 122, Highway Research Board, Washington, D. C., 1971.

Woods, Donald L. "Limitations of Phase Overlap Signalization for Two-Level Diamond Interchanges." Traffic Engineering, Vol. 39, No. 12, Sept. 1969, pp. 38-41.

Worrall, R. D., D. W. Coutts, H. Echterhoff-Hammerschmid and D. S. Berry. "Merging Behavior at Freeway Entrance Ramps." Northwestern University, Evanston, Illinois, 1965.

Worrall, R. D., J. S. Drake, J. H. Buhr, T. J. Soltman and D. S. Berry. "Operational Characteristics of Left-Hand Entrance and Exit Ramps on Urban Freeways." Highway Research Board Record 99, 1965, pp. 2440273.

Yates, J. G. "Relationship Between Curvature and Accident Experience on Loop and Outer Connection Ramps." Highway Research Board Record 312, 1970, pp. 64-75.

APPENDICES

APPENDIX A

QUESTIONNAIRES

APPENDIX A

Appendix A contains the following items:

1. A copy of the questions used in the personal interviews,
2. A list of the state highway departments which participated in this research,
3. The cover letter which was sent with both forms of the mailed questionnaire,
4. A copy of the questionnaire sent to the state highway departments,
5. A list of the highway design consultants who responded to the questionnaire, and
6. A copy of the questionnaire sent to the highway design consultants.

Questions Used in Personal Interviews

INTERCHANGE DECISION PROCEDURE

1. Do you have any unwritten policies on the type of interchange to use? For example: all diamonds; no cloverleafs in urban areas; others.

2. In your opinion what are the advantages and disadvantages of each basic type of interchange?

    a. diamond
    b. partial cloverleaf
    c. cloverleaf
    d. directional
    e. trumpet
    f. others

3. What process is followed in selecting the type of interchange to use at a particular location?

    a. Who makes what decisions?

4. Do you have a design manual which contains the steps to follow in the interchange selection process?

5. To what extent do you follow AASHO's Blue and Red Books in the interchange selection process?

6. What are the criteria that you use to determine the type of interchange to design? Do you have a specific evaluation technique?

7. The final decision on an interchange configuration is selected from how many alternative designs?

8. Do you provide for all movements in an interchange?

9. Does politics ever enter into the interchange selection process? The location of interchanges can be political but is the actual configuration ever influenced by political pressures?

10. Does topography affect the interchange type?

SYSTEMS APPROACH TO INTERCHANGE DESIGN

11. Are interchanges designed relative to adjacent interchanges?

12. Do you have an all right hand entrances and exits policy?

13. Do you follow the one-exit-only concept?

14. Are the possible interchange configurations a consideration in the initial route location process?

15. Is flexibility in design considered, a concept which takes into account the possible variations in traffic forecasts?

16. Do you follow the concepts of lane balance and basic number of lanes?

17. How do you design lane drops?

18. When does signing first receive attention in the design of an interchange?

CONSIDERATION OF THE CROSSROAD

19. How much consideration do you give to the crossroad in the design of the type of interchange?

20. Is the selection of the interchange type related to the functional use of the crossroad?

21. Is the "type of operation" on the crossroad a consideration in the selection of an interchange type?

22. What do you consider as the zone of influence of an interchange on the crossroad?

23. What is your access control policy on the crossroad?

24. Does the existing or potential land use development influence the interchange configuration?

25. Do you work closely with the area planning agencies?

26. Do you have a policy which requires a commitment by the responsible local agency to improve the crossroad approaching the interchange as a prerequisite to improve the crossroad between ramp terminals?

27. Do you build structures wider initially, both on the crossroad and on the freeway, as a part of stage construction or for possible future widening of the crossroad?

DETAILED DESIGN CONSIDERATIONS

28. How do you arrive at the design year volume?

29. In interchange design, do you use a 10 minute peak, 15 minute peak, design hour volume (DHV), or annual daily traffic (ADT or AADT)?

30. Do you use traffic volumes during both the a.m. and p.m. peaks or do you use volumes during one peak period and assume traffic flows are reversed during the other peak?

31. What design speeds do you use for interchange ramps?

32. When do you use a two lane ramp and when do you use two lane entrances and exits?

33. To determine the capacity or service volume, do you use the 1965 Highway Capacity Manual, the procedures in the AASHO Blue Book or a combination of the two?

34. Do you have any general capacity values which you apply to interchanges as a whole or to any element of an interchange?

    a. loop ramp
    b. diamond ramps, signalized and unsignalized
    c. merge areas
    d. diverge areas
    e. weaving sections
    f. diamond interchanges
    g. cloverleafs
    h. partial cloverleafs
    i. directionals
    j. others

35. What are your opinions toward the use of the following:

    a. frontage roads
    b. collector-distributor roads
    c. left hand ramps

36. Do you have any data which relate accidents to the type of interchanges or to an element of an interchange?

37. Is stage construction of interchanges used where applicable?

38. Is maintenance of traffic during initial construction an important consideration?

39. How do you try to eliminate wrong way maneuvers on interchange ramps?

40. What is your criteria for sight distance between decision points in an interchange area?

41. At off-ramps, do you provide full deceleration off the main line?

ECONOMIC CONSIDERATIONS

42. Do you have average cost figures for the various types of interchanges?

43. Do you have these cost figures based on type of topography?

44. What is the average land area required for each type of interchange?

45. If you had to economically justify one particular interchange configuration over another for a given site, what technique would you use?

46. Please define or explain the factors required in the technique described in question 45. For example, if accidents are included, what dollar value to you assign to the various types of accidents? If time is considered, what dollar value is assigned to a unit of time?

47. Which of the following techniques would you use or not use and why? 1. benefit-cost ratio; 2. road user benefits (costs);3. rate of return; 4. cost-effectiveness; 5. annual transportation cost; 6. other.

ENVIRONMENTAL CONSIDERATIONS

48. Do you have any way of measuring the aesthetic value of a particular interchange design?

49. How much additional cost and time can be associated with the current emphasis on the environment?

The chief state highway design engineer or his equivalent was interviewed in the states of California, Indiana, Illinois, Ohio, Michigan, and Texas. Questionnaires were mailed to the chief state highway engineer or his equivalent in the remaining forty-four states. The following thirty-four states replied:

Alaska	New Hampshire
Alabama	New Jersey
Arizona	New Mexico
Connecticut	New York
Delaware	North Carolina
Florida	North Dakota
Hawaii	Oklahoma
Idaho	Oregon
Iowa	Pennsylvania
Kansas	South Dakota
Kentucky	Tennessee
Louisiana	Utah
Minnesota	Vermont
Mississippi	Virginia
Missouri	West Virginia
Montana	Wisconsin
Nebraska	
Nevada	

Altogether, forty of the fifty state highway departments, or eighty percent, participated in this research project.

PURDUE UNIVERSITY
JOINT HIGHWAY RESEARCH PROJECT
CIVIL ENGINEERING BUILDING
WEST LAFAYETTE, INDIANA 47907

PURDUE UNIVERSITY
AND
INDIANA STATE HIGHWAY COMMISSION

I am working on a research project entitled "Guidelines for the Selection of Interchange Configurations". Mr. W. A. Wilson, Jr., Chairman of the Geometric Design Committee of the Highway Research Board, recommended this project and concurred that I should send out a short questionnaire as a means of expanding my data base.

I would appreciate it if you would have the appropriate person on your staff fill out the enclosed questionnaire. If possible, I would like to have these returned by the end of October.

Thank you for your cooperation.

Sincerely,

Thomas E. Mulinazzi
Graduate Instructor

TEM/lm

enc.

Questionnaire Sent to the State Highway Departments

GUIDELINES FOR THE SELECTION OF INTERCHANGE CONFIGURATIONS

1. Do you have any unwritten policies on the type of interchange to use? For example: all diamonds in rural areas; no cloverleafs in urban areas.

2. In your opinion what are the advantages and disadvantages of each basic type of interchange?

   a. diamond
   b. partial cloverleaf
   c. cloverleaf
   d. directional
   e. trumpet

3. Do you have a Design Manual? _____ Does it contain a section on the design of interchanges? _____ If yes, can I have a copy of that section?

4. Are the possible interchange configurations a consideration in the route location process?

5. Is the selection of the interchange type related to the functional use of the crossroad?

6. What is your access control policy on the crossroad?

7. What are the criteria that you use to determine the type of interchange to design? Example: turning volumes.

The following highway design consultants responded to the questionnaire:

1.	Alfred Benesch & Co.	Chicago, Ill.
2.	DeLeuw, Cather & Co.	Chicago, Ill.
3.	Edwards & Kelcey, Inc.	Newark, N.J.
4.	Glaus, Pyle, Schomer, Burns & DeHaven	Akron, Ohio
5.	Hazelet & Erdal	Louisville, Ky.
6.	Howard, Needles, Tammen & Bergendoff	Kansas City, Mo.
7.	Lochner & Associates	Chicago, Ill.
8.	Michael Baker, Jr., Inc.	Beaver, Pa.
9.	Mosure-Fok & Syrakes Co. Ltd.	Youngstown, Ohio
10.	Tippetts, Abbett, McCarthy, Stratton	New York, N.Y.
11.	no name	Indianapolis, Ind.

Questionnaire Sent to the Highway Design Consultants

GUIDELINES FOR THE SELECTION OF INTERCHANGE CONFIGURATIONS

1. In your opinion what are the advantages and dis- disadvantages of each basic type of interchange?

   a. diamond
   b. partial cloverleaf
   c. cloverleaf
   d. trumpet
   e. directional

2. Do you have your own design manual? Do you try to follow any particular state's design manual?

3. What are the criteria that you use to determine the type of interchange to design? Example: turning volumes.

4. Do you have any unwritten policies on the type of interchange to use? For example: no cloverleafs in urban areas.

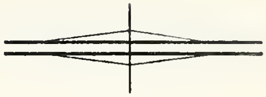
5. When would you use C-D roads?

6. For which states have you done work?

APPENDIX B

ADVANTAGES AND DISADVANTAGES OF SEVENTEEN INTERCHANGE CONFIGURATIONS

TIGHT DIAMOND



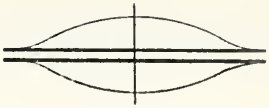
Advantages

1. good alignment standards
2. easiest to sign and operate
3. economical
4. minimum property requirement outside of normal right-of-way of the major road
5. one structure
6. no weaving
7. single exit from freeway
8. simplicity and good driver orientation
9. good capacity if ramp terminal flared
10. best liked by commercial interests
11. application in rural and urban areas
12. fits frontage road pattern
13. traffic can leave the main line at high speeds

Disadvantages

1. sight distance problems at ramp terminals on the crossroad
2. three phase signals
3. stop on crossroad for left turn
4. possibility of wrong way movement
5. at grade intersections at crossroad
6. all turning vehicles must stop

SPREAD DIAMOND



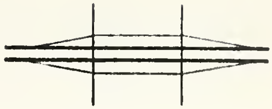
Advantages

1. good sight distance at ramp terminals on the crossroad
2. provides design flexibility; the opportunity to construct loop ramps with the interchange area
3. used where right-of-way is inexpensive - rural areas
4. economical
5. one structure
6. no weaving
7. single exit from freeway
8. simplicity
9. good capacity if ramp terminal flared

Disadvantages

1. requires more right-of-way than tight diamond interchange
2. not suitable for urban areas where right-of-way is restricted
3. stop on crossroad for left turn
4. possibility of wrong way movement
5. at grade intersections at crossroad

DIAMONDS WITH SURFACE STREET COUPLETS



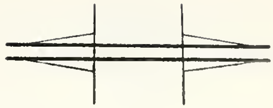
Advantages

1. minimum community disruption
2. economical
3. good driver orientation
4. good bypass in case of accidents
5. driver flexibility - more convenient alternatives to enter and leave freeway
6. fits a frontage road system

Disadvantages

1. closely spaced intersections on crossroad may cause capacity problems
2. slip ramps may cause operational problems on service road - weave problem
3. possibility of wrong way movements

SPLIT DIAMOND



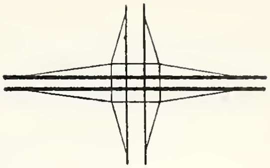
Advantages

1. two phase signals
2. usually services one-way pair
3. good driver orientation
4. simple turning movements
5. good signal progression can be provided in all directions
6. more storage and higher capacity than simple diamond
7. economical
8. good alignment standards
9. minimum right-of-way required
10. no weaving - single exit

Disadvantages

1. greater travel time
2. wrong way problems result if connected to two way streets
3. stop on crossroad for left turn
4. two structures required

MULTI-LEVEL DIAMONDS



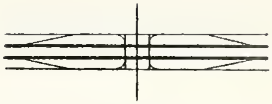
Advantages

1. two phase signals
2. highest diamond capacity
3. turning movements are all separated from the freeway and crossroad
4. used at major crossroads

Disadvantages

1. very expensive
2. a left turn requires a motorist to pass through three traffic signals

DIAMONDS WITH U TURN STRUCTURES



Advantages

1. increases capacity of the crossroad
2. removes U turns from the crossroad-service road intersections

Disadvantages

1. storage from signal may block access to U-turn structure
2. three phase signals

DIAMONDS WITH LEFT-TURN STRUCTURES

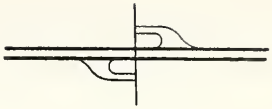
Advantages

1. left turns are removed from the crossroad-service road intersection
2. reduces crossroad laneage
3. greatly increases capacity
4. two phase signals

Disadvantages

1. circuitous driving pattern
2. can be confusing to unfamiliar driver
3. signing problems

PARCLO A



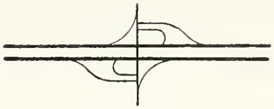
Advantages

1. no weaving on major road
2. single exit from major road
3. good design for unbalanced traffic movements
4. free flowing loop is on-ramp to major road
5. one structure
6. easily converted to Parclo A-4 or full cloverleaf
7. fits external controls

Disadvantages

1. unnatural right turn from minor road (turn left to go right): driver disorientation
2. left turns made off crossroad
3. requires channelization of crossroad
4. three phase signals
5. conducive to wrong way movements
6. can be confusing to the motorist
7. indirection in movement

PARCLO A-4



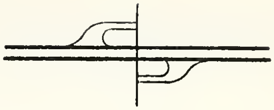
Advantages

1. no left turns on crossroad
2. two phase traffic signal operation
3. no weaving on major road
4. single exit from major road
5. reduced possibility of wrong way movements
6. one structure
7. loop ramps serve as on-ramps to freeway
8. movements off crossroad are all free flowing right turns
9. capacity greatly increased over diamond and Parclo A
10. stop for left turns confined to ramps only
11. signal spacing further than on tight diamond
12. two on-ramps and one off-ramp from freeway
13. good design for unbalanced traffic movements

Disadvantages

1. requires more r.o.w. than simple diamond
2. signals may be required on minor road when through and turning volumes (urban area) are high
3. conversion to full cloverleaf may be costly
4. confusing to the motorist
5. indirection in movement

PARCLO B



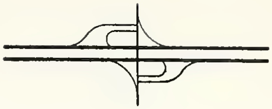
Advantages

1. no weaving on major road
2. one structure
3. single exit from major road
4. not conducive to wrong way movements
5. all movements from minor road natural
6. fits external controls
7. good design for unbalanced traffic movements

Disadvantages

1. left turns off of crossroad
2. loop ramps beyond structure have been hazardous
   a. sight distance
   b. change in design speed from through lane to loop ramp
3. three phase signals
4. loop ramp is off ramp from freeway
5. free flow loop terminal on crossroad can cause problems
6. confusing to the motorist
7. indirection in movement

PARCLO B-4



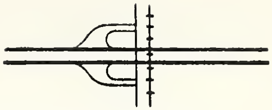
Advantages

1. two phase signals
2. no weaving on major or minor road
3. one structure
4. all movements are natural
5. good design for unbalanced traffic movements

Disadvantages

1. double exit off the freeway unless a partial C-D is provided
2. left turns still made off crossroad
3. loop ramp is off-ramp from freeway
4. possible wrong way movements
5. conversion to full cloverleaf may be costly
6. high property requirements
7. free flow loop terminals on crossroad can cause problems
8. confusing to the motorist
9. indirection in movement

PARCLO A-B (Half cloverleaf)



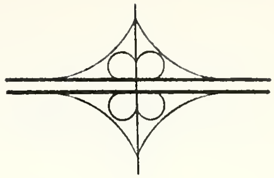
Advantages

1. used if right-of-way is restricted by railroad, river, land use, etc. on one side of the crossroad

Disadvantages

1. weave introduced on crossroad
2. three phase signals
3. indirection in movement because of loop ramps

FULL CLOVERLEAF



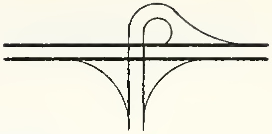
Advantages

1. all movements are free-flow
2. "lowest" type of system interchange
3. no left turn movements on ramps or crossroad

Disadvantages

1. loops have limited capacity
2. tight weave sections on the mainline and on the crossroad
3. takes a large amount of right-of-way
4. should not be used for service interchange
5. free flowing exits often cause problems on the crossroad, especially with weaving to the adjacent intersections
6. requires the additional cost of C-D roads
7. two exits and two entrances
8. indirection in movement
9. high construction and r.o.w. costs

TRUMPET A



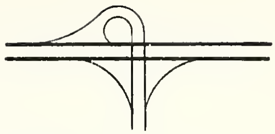
Advantages

1. loop serves as on-ramp to the freeway
2. can handle large directional volumes
3. fits traffic flow pattern

Disadvantages

1. difficult to extend truncated approach if demand develops
2. should not be used for freeway-to-freeway connection
3. minor movement on loop can have an accident problem
4. indirection in movement

TRUMPET B



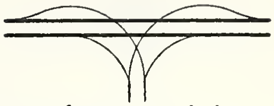
Advantages

1. fits traffic flow pattern
2. can handle large directional volumes

Disadvantages

1. loop ramp is off-ramp from the freeway
2. should not be used for freeway-to-freeway connection
3. difficult to extend truncated approach if demand develops - not flexible
4. minor movement on loop can have an accident problem
5. indirection in movement

DIRECTIONAL T OR Y



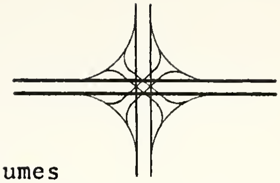
Advantages

1. use for all freeway to freeway interchanges with three approaches
2. can handle large directional volumes

Disadvantages

1. backward movements should be provided
2. left hand ramps usually included
3. signing can be a problem

4-QUADRANT DIRECTIONAL



Advantages

1. can handle large directional volumes
2. used for system interchanges except where volumes are low and where a 4 quad cloverleaf interchange with C-D roads can be used
3. maintains route continuity
4. minimizes the speed differential between the through lanes and the ramps

Disadvantages

1. high construction and right-of-way costs
2. left hand ramps may be included
3. weaving sections may be developed
4. do not use for service interchange
5. loop ramps may be used for minor flows
6. isolates land adjacent to interchange because of the lack of local access
7. internal service ramps may become a necessity
8. requires a lot of land

APPENDIX C

DISCUSSION OF COST-EFFECTIVENESS TECHNIQUE

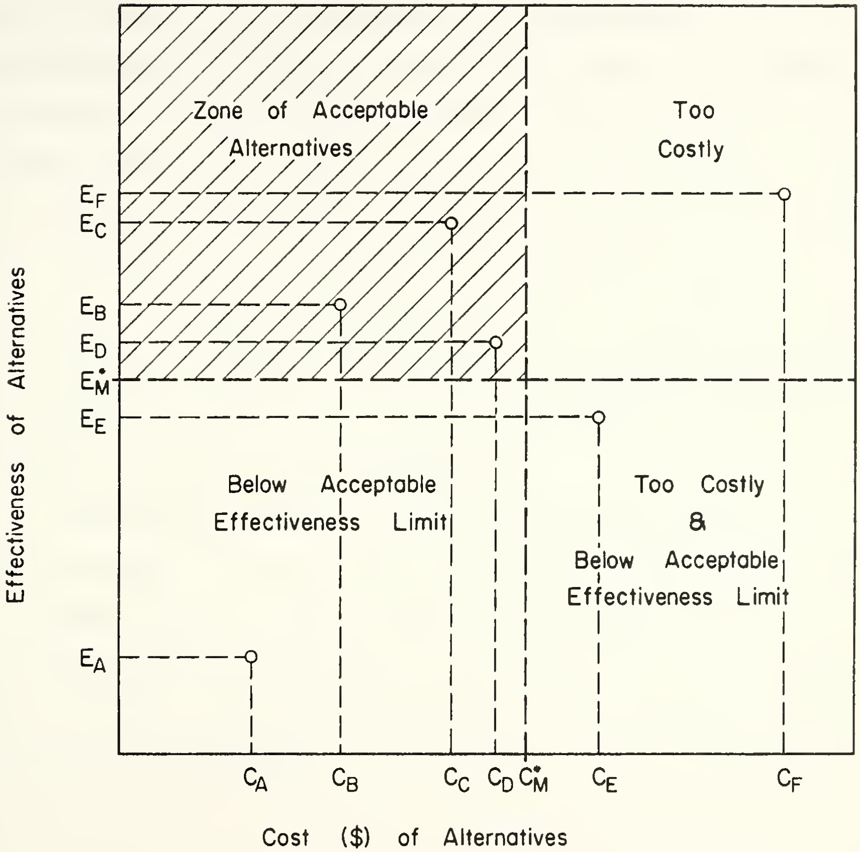
Cost-Effectiveness Approach

In general, a cost-effectiveness analysis is conducted to determine the best return for a capital investment of a given set of alternatives to a given problem. Costs can be measured in several ways but are usually in terms of dollars, as is the case in this research. Effectiveness can be in terms of both quantifiable and qualifiable criterion; a fact which makes this technique very appropriate in the interchange configuration selection process because many of the evaluation criteria are unmarketable or qualifiable in nature.

Figure 8 illustrates the basic concept of cost-effectiveness. Alternatives A, D, E, and F can be quickly eliminated because:

1. Alternative A does not meet the minimum effectiveness constraint.
2. Alternative D is dominated by both alternatives B and C; i.e. for an increase in cost there is a reduction in the return.
3. Alternative E is too costly besides not meeting the minimum effectiveness constraint.
4. Alternative F is too costly although it does meet the minimum effectiveness constraint.

With no other data, alternative B might be considered a good solution because it has an acceptable return for a low cost. However, alternative C might also be considered a good



*E_M = Minimum Effectiveness Acceptable, C_M = Maximum Cost

FIGURE 8 BASIC CONCEPT OF COST-EFFECTIVENESS TECHNIQUE

choice if the additional cost can be justified by the increase in the return or effectiveness measure.

The cost-effectiveness approach is readily applicable in this research because cost figures can be determined for each different type of interchange configuration, and the effectiveness of different interchange configurations varies depending on the evaluation criteria selected. In this project costs only include initial costs - construction, right-of-way, relocation of utilities, families, businesses, etc. Effectiveness is measured in many ways, depending on the types of evaluation criteria which are applicable to the given design situation. The several effectiveness measures recommended in this project can be found in the list of evaluation criteria found in Chapter 5.

A generalized example of the application of the cost effectiveness technique in this research is given in Figure 9. In this case the effectiveness measure has a negative input into the decision process: the higher the effectiveness rating the more of a disturbance there will be to the surrounding environment.

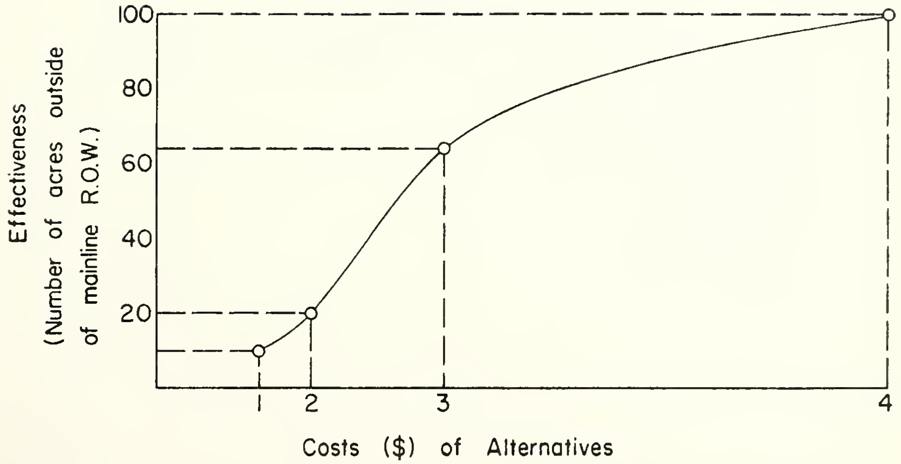


FIGURE 9 APPLICATION OF COST-EFFECTIVENESS TECHNIQUE

APPENDIX D

SAMPLE APPLICATION OF EVALUATION METHODOLOGY

APPENDIX D

SAMPLE APPLICATION OF THE EVALUATION METHODOLOGY

This sample is presented to expand the discussion of the evaluation methodology contained in Chapter 6. The cost values and the evaluation criteria used are not inviolable and should not be directly applied in the evaluation of any other interchange design situation. The interchange designer must determine what cost figures and which evaluation criteria are appropriate for his particular interchange design situation.

The example is an evaluation of three interchanges designed by individual graduate students as a class requirement for the advanced geometric design course at Purdue University. The students were directed to design a service interchange, providing all movements between a major state highway and a limited access facility. The design was complicated by the presence of a river paralleling the state highway on the east and an elevation difference of over 170 feet from the river's flood plain to the top of the bluff on the west side on the state highway, as shown in Figure 10. The existing site constraints were the nearby high priced housing, the presence of a mental sanitarium and a senior

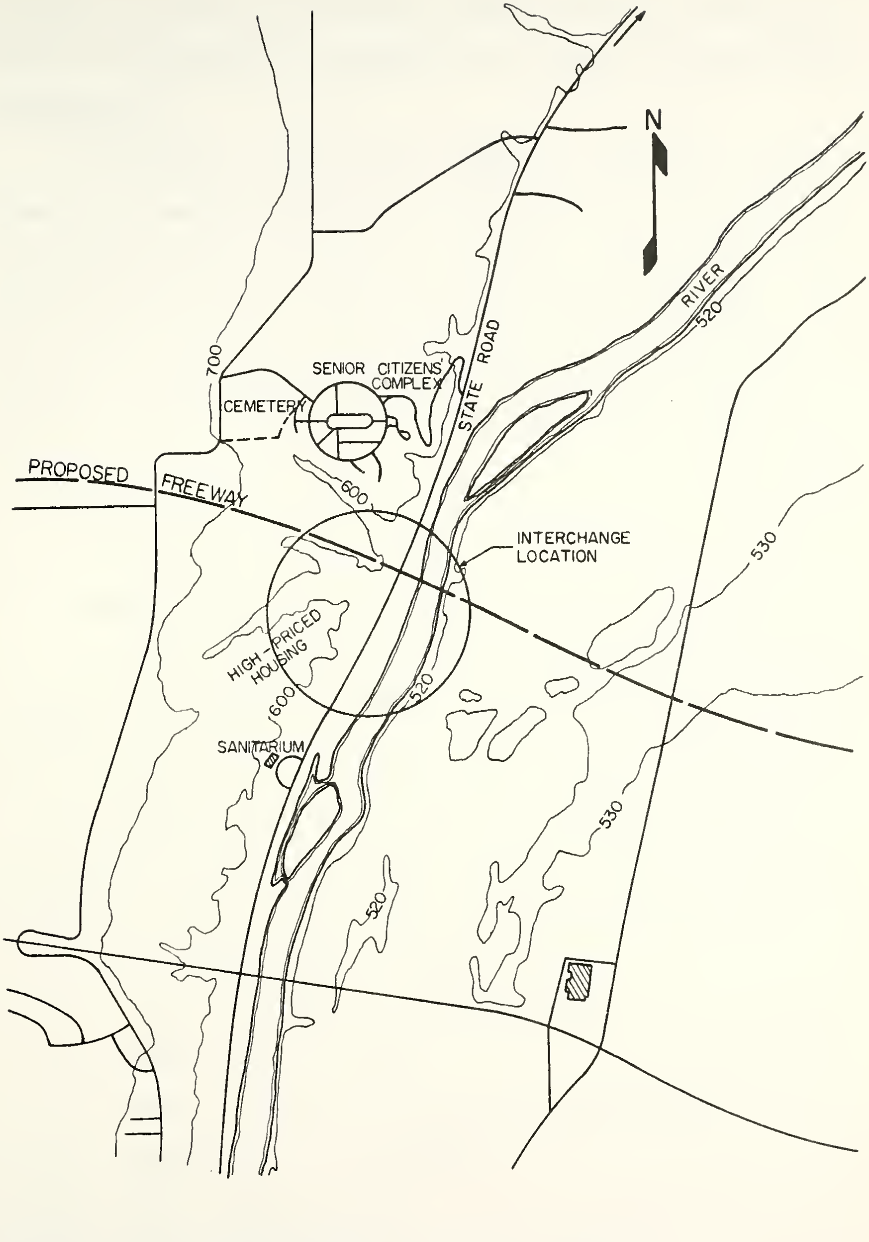


FIGURE 10 INTERCHANGE LOCATION MAP

citizens' complex, the natural beauty of the river bluff, and the maintenance of traffic on the state highway during construction.

The 1998 p.m. peak hour volumes are shown in Figure 11. The unit construction costs and the general design considerations which governed the students' designs are listed in Tables 13 and 14. Figure 12 illustrates the three alternative interchange configurations being compared. The initial costs for the three alternative designs were as follows:

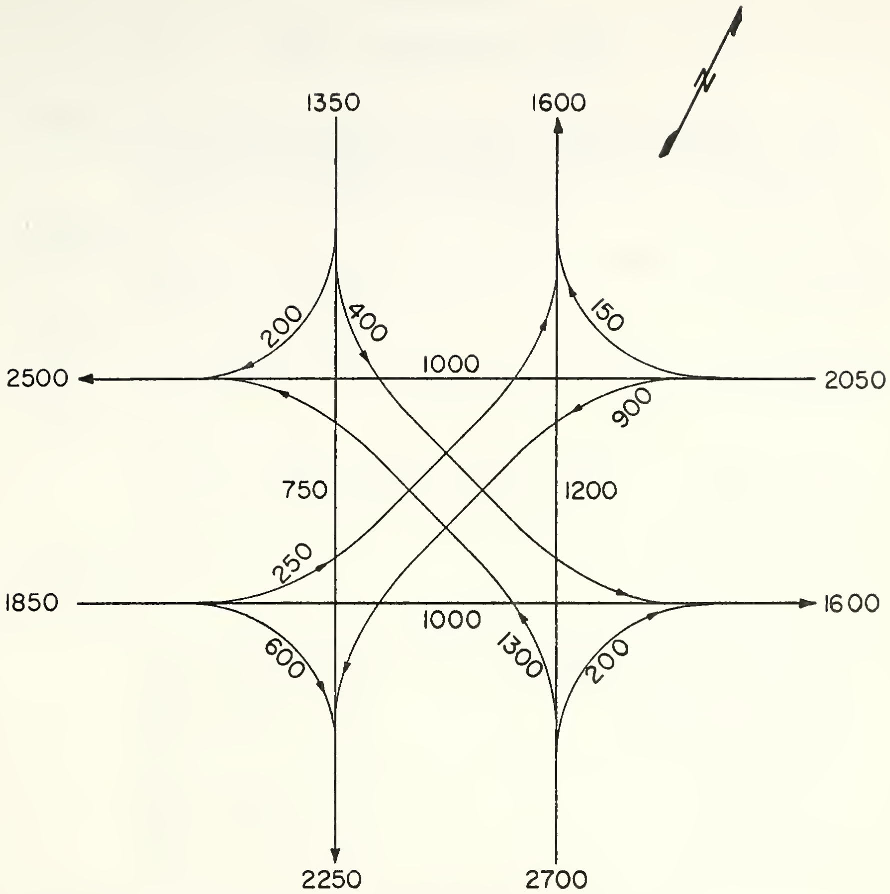
Alternative 1 - $15,520,095

Alternative 2 - $14,989,740

Alternative 3 - $16,251,218

Based on the interchange design philosophy developed through this research and after analyzing the design situation and the many possible evaluation criteria, the following criteria are selected for inclusion in the evaluation methodology because they are a measure of the differences between the three alternative interchange configurations:

1. level of service on the freeway
2. level of service on the crossroad
3. number of structures
4. total length of structures in stations
5. complexity of structures
6. cubic yards of cut
7. cubic yards of fill



T = 5 %

Design Vehicle = WB-50

FIGURE 11 1998 P.M. PEAK HOUR VOLUMES

TABLE 13

UNIT CONSTRUCTION COSTS

General per mile of freeway for all width of R.O.W. (maintaining pavement, sidewalk, curb; aluminum chain link fence; fine grading and clean up, sodding and seeding, restoring roadsides)	\$94,000/mi
General per acre (removing trees, removing concrete, pavement, backfilling basements)	\$ 940/acre
Seeding and mulching	\$ 500/acre
General lighting on freeway or expressway	\$125,000/mi
lighting on turning roadways	60,000/mi
Utility adjustments	
(sewer, water, public lighting)	
For freeway ROW 350 to 449'	\$800,000/mi
For freeway ROW 450 to 500'	\$1,000,000/mi
Earth Excavation	\$0.75 cu. yd.
Bridges	
Vehicular Bridge (open end span)	
Total Width under 70'	ft^2 of deck
Span under 80'	\$19/sq ft
Span 80' to 100'	\$20/sq ft
Span 100 to 140'	\$25/sq ft
Total Width over 70'	
Span under 80'	\$16/sq ft
Span 80' to 100'	\$17.50/sq ft
Span 100 to 140'	\$22.50/sq ft
Pavement on Freeway and Turning Roadways	
Pavement 10" reinforced PCC including subbase	
12' wide	\$16/ft
24' wide	\$32
36' wide	\$48
48' wide	\$64
60' wide	\$80
Curb and gutter	\$3.30/lin ft
Median end shoulders on Freeway and Expressway	
2 paved shoulders (10' each) and one 30' median (including drainage and double beam steel guard rail)	\$65/ft
2 paved shoulders (one 10' and one 4') and drainage for turning roadways	\$25/ft
Drainage on Freeway or Expressway	\$35/ft

TABLE 14

GENERAL DESIGN CONSIDERATIONS

	FREEWAY	STATE HIGHWAY
DESIGN SPEED	70 mph	60 mph
MAXIMUM SUPERELEVATION	0.08 ft/ft	0.08 ft/ft
MAXIMUM DEGREE OF HORIZONTAL CURVATURE ON THROUGH ROADWAYS	3°	4°
MAXIMUM VERTICAL GRADIENT ON THROUGH ROADWAYS	3%	4%
MAXIMUM VERTICAL GRADIENT ON RAMPS	6%	

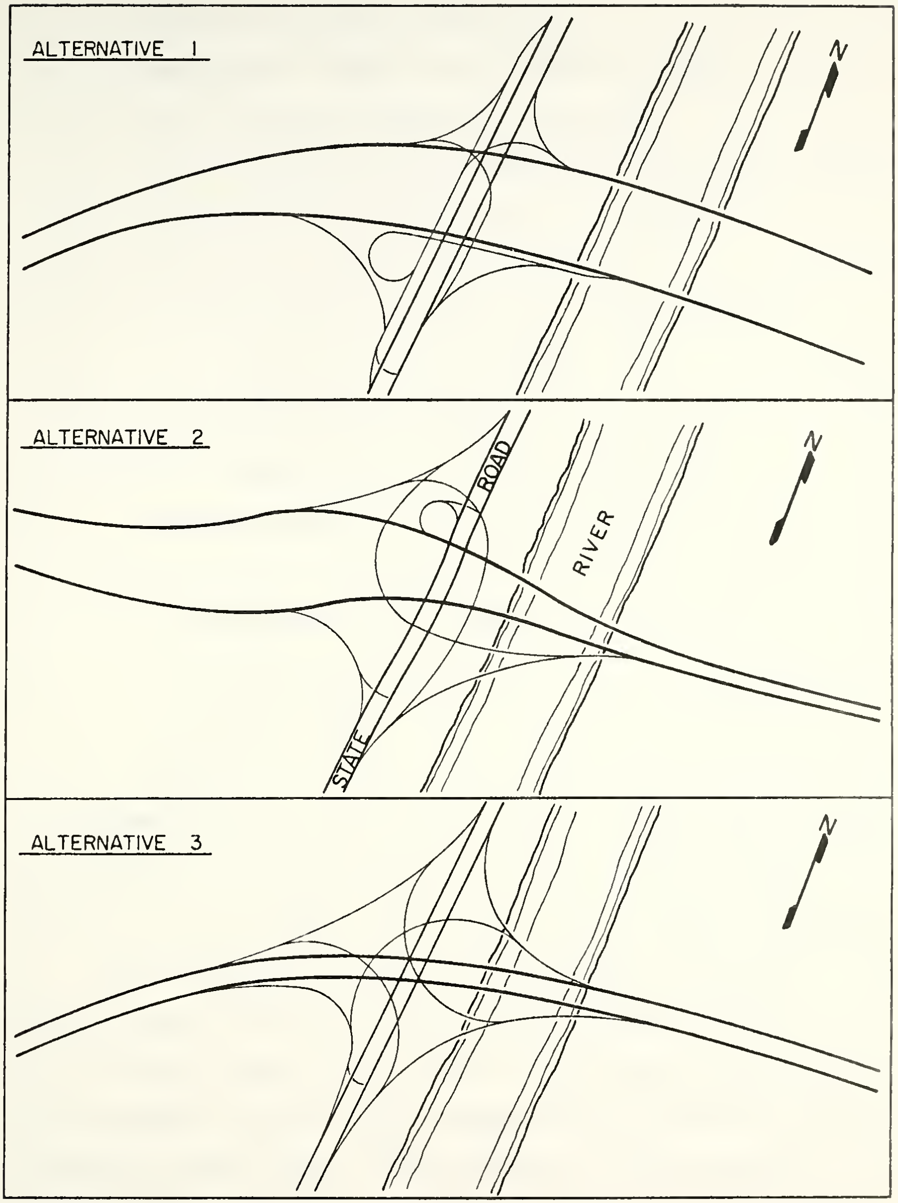


FIGURE 12 ALTERNATIVE INTERCHANGE CONFIGURATIONS

8. number of families relocated
9. additional right-of-way needed in acres
10. total length of ramps in stations
11. total length of ramps with over 5% grade in stations
12. disruption to senior citizens' complex
13. design and operational flexibility
    a. maintenance of traffic on state highway
    b. number of weaving sections
    c. number of loop ramps
    d. conduciveness to stage construction
14. design uniformity
    a. on and off ramp design
    b. adaptability to signing
    c. crossroad operations
    d. lane continuity
15. safety

These pertinent evaluation criteria are utilized in the development of an Effectiveness Profile for the three alternative interchange configurations, as shown in Figure 13. Some of these criteria have a minimum acceptable effectiveness limit and any alternative design whose effectiveness rating falls below this minimum acceptable effectiveness limit for any evaluation criterion should be eliminated from further consideration. These absolute minimum limits should be established prior to the development of the Effectiveness Profile. There are five such

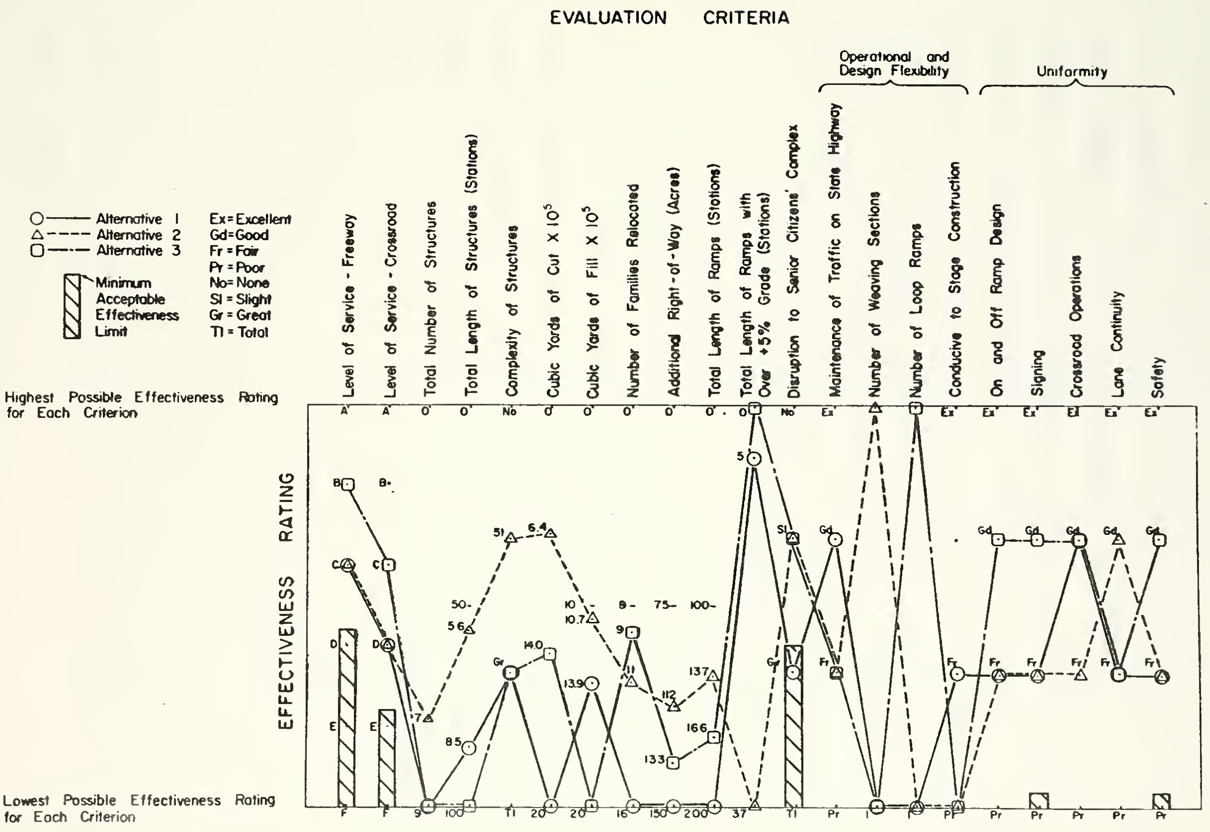


FIGURE 13 EFFECTIVENESS PROFILE

constraining limits in Figure 13. The final interchange configuration must maintain at least a level of service C on the freeway and ramps and a level of service D on the state highway, based on the design year traffic. It is also important that the disturbance to the senior citizens' complex be kept to a minimum. Very little disruption can be tolerated. A higher than poor rating must be obtained for the signing and safety criteria. The interchange must be signable to operate efficiently and should meet minimal safety standards. Each evaluation criterion is represented by a vertical scale which has its own scaling factor; some are numerical - total length of structures in stations; and some are subjective - lane continuity expressed as excellent, good, fair or poor. The highest or best possible effectiveness rating for each criterion is plotted on the top of the appropriate vertical scale or along the top abscissa of the graph. If is not possible to state the best effectiveness rating for a criterion, then the best or highest actual effectiveness rating of the alternatives is plotted at the top of the scale. This situation did not occur in the example. The lowest possible or worst effectiveness rating for each criterion is plotted at the bottom of the scale; for example, at level of service F on the freeway and on the crossroad or a poor manner of maintaining traffic on the state highway.

If no lowest effectiveness rating can be established, then the lowest of the actual effectiveness ratings for the alternatives is plotted on the bottom abscissa. For example, the total length of structures, the amounts of cut and fill, the number of families relocated and the additional right-of-way along the state highway are plotted this way. Whatever the type of scale used, each point in Figure 13 represents the effectiveness rating of a particular alternative interchange configuration for a given evaluation criterion. By connecting the individual points for an alternative design, an effectiveness profile is developed for that alternative. By plotting two or more of these Effectiveness Profiles on one graph, an accumulative Effectiveness Profile, which provides an easy comparison of alternative interchange designs, is developed.

Because of the subjectivity and attributes of some of the evaluation criteria, it is felt that a brief explanation is needed to illustrate how some of the effectiveness ratings were determined. Since each student had performed a capacity analysis on his interchange design to assure that it could handle the 1998 forecasted traffic, at least the minimum operational constraint was satisfied. However, the level of service on the freeway and on the crossroad are considered evaluation criteria because one student designed for a minimum level of service B on the freeway and C on the crossroad while the other two used a minimum level of service

C on freeway and a minimum level of service D on the crossroad. All three students maintained a level of service continuity on the freeway and on the crossroad. These two level of service criteria are important because the interchange configuration increases in cost as the designer bases his design on a higher level of service; level of service "F" being the lowest and "A" being the highest.

With the river on one side of the state highway and the abrupt hillside on the other, the number, total length and complexity of structures have a bearing on the eventual interchange configuration. These evaluation criteria indicate the compactness of the design, the location of the ramps to the river and how the design fits the topography.

The cubic yards of cut and fill are used as evaluation criteria to also represent how the interchange fits into the topography. The objective is to minimize the amount of cut and fill, thereby causing the least disturbance to the natural hillside.

All three designs miss the high priced housing on the bluff in the southwest quadrant. However, the number of other families relocated is selected as an evaluation criterion. Because of the new alignment of the state highway proposed in Alternative One, this solution requires the relocation of sixteen families, and the taking of an additional 150 acres of right-of-way. The taking of additional right-of-way is critical because of the

topographic constraints placed by the river, the narrow flood plain, the bluff and the adjacent land uses.

The total length of ramps and the total length of ramps with a 5% or greater upgrade are chosen as measures of compactness and operational efficiency. These values are obtainable from the ramp profiles.

Alternative One brings excess disruption to the senior citizens' complex by drastically cutting into the bluff just below the existing buildings. The public, with representatives from the senior citizens, would not allow such a design without an extensive struggle based on this detrimental environmental impact. The other two alternatives slightly infringe upon the property.

It would be difficult to maintain traffic during construction on the state highway with Alternatives Two and Three; and there is no feasible way to reroute the traffic. However, Alternative One solves this problem by relocating the state highway so that traffic can use the existing pavement throughout much of the construction period.

Alternatives One and Three each have one high volume weave section. In Alternative One the weaving section, carrying a peak hour volume of 1750, occurs on the collector-distributor road. This weaving section probably would not work. The weaving section in Alternative Three carries 1150 vph and is located on the ramps in the southwest quadrant. Both weaving sections are too short for the anticipated volume.

Loop ramps are found in two of the three alternatives. In Alternative One the loop ramp serves the south to east movement with a design hour volume of 450 vph. The loop ramp connects the state highway to the freeway and is used in conjunction with a C-D road. The loop ramp in Alternative Two carries the west to south movement, functioning as an off-ramp from the freeway. From a speed continuity concept, this design practice is poor.

None of the alternative designs adapt themselves readily to stage construction. Only Alternative One has a fair possibility of attaining some form of stage construction.

The concept of uniformity is followed to some degree by all three alternative designs. Since the design situation is an isolated location, it is not possible to analyze ramp uniformity along the freeway system. Alternative Three has the best design for the on and off-ramps. It follows the one exit only concept and has all right hand ramps, which are long and flat. Alternative One has a left hand on-ramp to a collector-distributor road, resulting in heavy volumes and weaving on the C-D road. The loop off-ramp from the freeway in Alternative Two is a weak link. Also, the west to north movement takes off from the outside of the loop ramp.

The signing problems are directly related to the on and off-ramp design. Alternative Three should be easy to sign while Alternatives One and Two will present some signing problems.

The crossroad operations should be good for Alternative One and Three. They both require one traffic signal with a 50 to 60 second cycle. Alternative Two calls for two traffic signals with 100 second cycles, which are too long. There are also four places where traffic departing from the freeway interferes with the south bound traffic on the crossroad.

The concepts of lane balance and basic number of lanes are followed by the students. However, Alternatives One and Three have lane drops where the east to south ramp diverges from the freeway.

Safety could be a problem with Alternative Two. The loop off-ramp from the freeway and the two traffic signals on the state highway could result in accidents. These would be the only traffic signals for miles. Alternatives One and Three have weaving sections in the southwest quadrant which could be hazardous, especially in Alternative One where the volume reaches 1750 vph. These two alternative designs also have a greater than 0.3 reduction in design speed from the freeway to the west to south semi-directional ramp.

The impact on the mental sanitarium is not used as an evaluation criterion because all three configurations do not interfere with the sanitarium. The same is true with the high priced houses on the bluff and the cemetery behind the senior citizens' complex. Operating cost is not employed as an evaluation criteria because all three alternatives have

about the same annual operating cost. The same is true for maintenance costs.

Based on the Effectiveness Profile, Alternative One can be eliminated from further consideration because it violates one of the constraints by causing too much disruption to the senior citizens' complex; unless upon analysis, the disturbance to the senior citizens' complex is found not to be as important as it once was thought to be. This decision should be left up to the general public to decide, either through the public hearings or through committee action.

The real decision then is between Alternatives Two and Three. The differential in initial costs between these two alternatives is $1,261,478 or about 8.5%; Alternative Two costs $14,989,740 and Alternative Three costs $16,251,218. If the initial costs of both alternative designs are economically feasible then the decision must be made based on operational, design, and community factors.

Table 15 summarizes the best attributes of both alternative designs and lists some of their similar characteristics. From this table it is evident that Alternative Two fits the topography better and is more compact. In general, it is a better design when considering design factors. Alternative Three rates higher when only the operational factors are considered. It provides a higher level of service on both facilities, better ramp design, an easier configuration to sign, better crossroad

TABLE 15

COMPARISONS OF ALTERNATIVE DESIGNS

Alternative Two	Alternative Three
1. fewer structures	1. higher levels of service on the freeway and crossroad
2. less total length of structures	2. less families relocated
3. less complicated structures	3. flatter ramp grades
4. less borrow needed	4. no loop off-ramps from the freeway
5. requires less right-of-way	5. better on and off-ramp design
6. less total length of ramps	6. easier to sign
7. no weaving sections	7. better crossroad operations
8. better lane continuity	8. safer traffic operations

Similar Characteristics

1. slightly disruptive to senior citizens' complex
2. difficult to maintain traffic on state highway
3. not conducive to stage construction

operations and safer overall traffic operations. The basic question is whether the additional cost, an 8.5% increase, can be justified in order to provide better traffic operations.

Alternative Two has a split right-of-way on the west approach. This allows, the separate roadways to better fit the topography, but the land in between would have to be purchased by the highway department and not left in private ownership as proposed by the student. This would increase the cost of Alternative Two.

Alternative Three provides much more operational flexibility. By designing for higher levels of service on the freeway and on the crossroad, future traffic volumes can exceed the forecasted volumes and still the interchange should operate above the minimum acceptable effectiveness limits. The major operational weaknesses in Alternative Three are the high volume weaving section in the southwest quadrant and a lane drop in the interchange area. These poor characteristics are more than counterbalanced by the other positive operational characteristics of the design.

Based on the interchange design philosophy presented in Chapter Four, Alternative Three is the recommended configuration. It satisfies the minimum design and community disruption criteria while providing a safer, and more flexible traffic operational environment.

VITA

VITA

Thomas Ernest Mulinazzi was born on April 3, 1942, in Ottawa, Illinois. His primary and secondary education was acquired in Ottawa where he was graduated from Marquette High School in 1960.

He received the Bachelor of Science in Civil Engineering Degree from the University of Notre Dame in 1964 and the Master of Science in Civil Engineering from Purdue University in 1966. He continued his education on an Automotive Safety Foundation Fellowship at Purdue until January, 1968, at which time he joined the staff of the Louisville Metropolitan Comprehensive Transportation and Development Program as head of the Transportation Studies Division. In October 1969, he joined the civil engineering consulting firm of Schimpeler-Schuette Associates in Louisville as an Associate of the firm. In September 1971, he returned to Purdue to complete his education.

He is an Associate Member of the Institute of Traffic Engineers, a Junior Member of the American Society of Civil Engineers and a Supporting Member of the Highway Research Board. He also belongs to Chi Epsilon and Tau Beta Pi.

He is married and has two children.